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ON

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MINE DRAINAGE

BEING

A COMPLETE PRACTICAL TREATISE

ON

DIRECT-ACTING UNDERGROUND STEAM PUMPING MACHINERY

BY

STEPHEN MICHELL

JOINT-AUTHOR OF ESSAYS ON 'THE BEST MINING MACHINERY' AND 'THE CORNISH SYSTEM OF MINE DRAINAGE'

SECOND EDITION, REWRITTEN AND ENLARGED

WITH NUMEROUS ILLUSTRATIONS

LONDON

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PREFACE

TO

THE SECOND EDITION

THE period that has elapsed since the First edition of this work made its appearance has been characterised by considerable activity in the domain of pump design and manufacture, and by the adoption of higher ranges of steam pressure, as the succeeding pages will attest. Many of the engines in use when the work was first published have in the severe ordeal of underground work maintained their position as useful and effective pumping agents; others have failed, and are now only a name in the chronicle of mine pumps. But the introduction of new types has gone on apace, and we are to-day in the presence of a bewildering variety of steam-pumping appliances.

In preparing this new edition, the Author has endeavoured to give expression and consideration to these changes and developments in Underground Steam-pumping Machinery commensurate with their importance. He says 'underground' advisedly, as 'surface' engines are only referred to incidentally and for the purpose of comparison.

Great pains have been taken to reach original sources of information in British and foreign mines, with the object of gathering authentic and definite knowledge on the cost, duty, and durability of engines in actual use. Whilst much of the matter

received is of general utility and value, little information on the points named has been communicated. It would, in fact, appear that very little knowledge can be gleaned in any direction as to the first cost of pumps, boilers, and their adjuncts, as to the expense of installation in the shaft, or as to their economic results. Manufacturers generally, to avoid 'giving points' to their competitors, have ceased to supply open quotations, except for medium and small pumps; indeed, some leading manufacturers will, for any size engine, only quote on a *bonâ fide* specification, and mine and colliery managers, for one reason or another, are rarely disposed to give any information relative to the cost of their pumping plant. Nor is it less difficult to get from mining authorities the 'duty' results of engines; in only a few instances have authentic data hereon been obtained.

This experience appears to be by no means unique; other writers in this and other departments of mine engineering have had the same difficulty when their quest has been actual facts and figures.

Of late years mine and colliery engineers have given greater attention than formerly to the working economy of underground engines. This has led to the more frequent adoption of compound engines—and in a few instances of triple-expansion engines—for heavily-watered workings. Improvements have been effected in the general construction of the engines, and greater care and finish have been bestowed upon the details; higher grades of steam-pressure have been introduced, with extra precautions against loss by radiation from steam-cylinders and pipes. All along the line progress has been 'writ large' upon the mine-pumping appliances of the present decade.

Perhaps the most interesting developments have been the adoption of the American Duplex principle of pump, and the employment of Electricity as a pump motor. Opinions differ as to the superior economy of duplex compared with simple pumps, and—

having regard to the extra cost and complication of parts and the greater space required—as to the advantage of triple-expansion over compound engines. These matters are dealt with in the following pages.

Electricity, as a motor, commends itself because of its handiness and convenience in dealing with water in remote, out-of-the-way, and more or less inaccessible places, such as winzes, dips, etc., and for experimental work, but its suitability for heavy permanent drainage is not so apparent.

Holman's air winch, a very useful adjunct to pumping plant, has been introduced into the principal Cornish mines with very satisfactory results. A description of this handy little appliance will be found in the Appendix.

Only a brief reference to Hydraulic pumps will be found in the Appendix, and a similarly short account of the useful work done by Electric pumps. It was found that to deal with these matters as fully as their importance demanded would occupy too large a space in the present volume, and seriously delay its issue. Indeed, a separate volume would be necessary for an adequate treatment of such pumps.

Although the last-mentioned subjects have necessarily only been briefly considered, the Author trusts that in its present revised and extended form the work may prove of continued and increasing service to mine managers, students of mining, and all others interested in the important question of Mine Drainage.

He begs thankfully to acknowledge the valuable help which has been given him in the collection of material for the new edition by Mr. Jebus Bickle (of Bickle & Co., Ltd., Plymouth), and Mr. Chas. H. Blight, of the Hayle Foundry ; also the kindness and courtesy of Mr. William Thomas, F.G.S., Assoc.M.I.C.E., M.I.M.M., Lecturer on Mining at the Camborne School of Mines, and Mr. Nicholas Trestrail, Assoc.M.I.C.E., of Redruth. To how many mining authorities in other countries the Author is indebted for

valuable information the succeeding pages witness. To all of these, and to others who have kindly helped, he begs to tender his sincere thanks.

Many of the illustrations have been specially prepared for this work, but a great number are from blocks courteously lent by manufacturers, whose kindness the Author now begs to acknowledge. Thanks are specially due to Messrs. Tangyes, Limited, for the numerous electros kindly lent for reproducing figures appearing in their copyright catalogue. Messrs. Hayward-Tyler & Co., Hathorn, Davey & Co., Blake & Knowles, Ltd., the Worthington Engine Co., W. H. Bailey & Co., Ltd., Jos. Evans & Sons, Frank Pearn & Co., Ltd., the Pulsometer Engineering Co., Ltd., John Cameron, Ernest Scott & Mountain, Ltd., and others, have also very kindly placed electros at the Author's service.

HAYLE : *June* 1899.

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UNDERGROUND
STEAM PUMPING MACHINERY.

INTRODUCTION.

For many generations the Cornish engine has maintained undisputed pre-eminence for the drainage of mines, and in all parts of the civilised world has been found the ponderous structure dipping its enormous trunk low down into the bowels of the earth and lifting to light the fountains of the deep; and so for a century it has pioneered the way for the adventurous miner, and enabled him to reach the vast mineral wealth lying deep in the earth's crust. From the moment Watt made the machine a perfect instrument it has known, practically, no rival until the last quarter of the century. Unexcelled, perhaps unapproached, for permanent and deep and extensive drainage, it was too costly and massive for minor pumping operations, and the ingenuity of the engineer has been taxed to produce a machine that would by its small size, compactness, portability, and general handiness, together with its comparatively low cost, be suitable for drainage under special circumstances, and also for experimental mining work. The application of thought, and the growing knowledge of an ever-advancing civilisation during the present reign, have left their impress upon our commercial history in the particular branch of mechanics we are considering, in the invention and subsequent development of many forms of pumping machinery designed to meet this want. The central idea of engineers has been to establish a closer and more direct connection between the motive power and the matter to be moved; in other words, to unite the engine and the pump in a direct manner, making a solid and compact machine, a veritable *multum in parvo*. Thanks chiefly to the genius of Worthington, Knowles, Blake, and Cameron, all American engineers, the idea has been splendidly achieved in the invention and perfection of those machines known as steam-pumps, the first of which made its appearance in the year 1844. In the Great Exhibition of 1851 there was only one steam-pump exhibited. It had a vertical cylinder and a fly-wheel.

There is an almost bewildering variety of steam-pumps, resolvable into two great groups—namely, Horizontal pumps and Vertical pumps, each divisible into Rotary and Non-Rotary.

The Horizontal group, which is the more important, may be subdivided into Simple, Compound, and Triple Cylinder Engines; the first embrace by far the greatest number of machines, which are very similar in construction and mode of action, the main point of difference being in the steam-valve gear. This is the most important class of Simple Pumps, and many thousands are in use in this and other countries, not only in mines, but in tanneries, chemical works, water works, etc. The second and third are more economical classes than the single-cylinder engines, having been introduced to economise the consumption of fuel.

Vertical Steam-Pumps are very useful for all or most of the purposes for which the horizontal pumps are more generally used, and for pumping under certain circumstances they are preferable. Some of the varieties of these pumps are merely the ordinary horizontal steam-pumps arranged to work vertically.

Although not suitable for all pumping operations—no machines are—steam-pumps occupy nevertheless a high position amongst modern pumping appliances, and have rendered important services in the prosecution of mining, particularly in experimental operations in the opening up of new mines, and in sudden emergencies such as the breakage of other pumping machinery, and the flooding of underground workings. It is well-known what valuable services these pumps performed at Tynewydd, when the water broke in from an adjoining colliery, flooded the bottom workings, and imprisoned several men.

DEFINITION.

Before proceeding to discuss the qualities of steam-pumps, it will be necessary to propose the question—What is a steam-pump? An answer is not easily found; the term is so elastic and so loosely applied, and may be made to comprehend so much. It may be observed that machines of precisely similar character bear different names. One maker will call his machine, say, the 'Victoria' Steam-Pump, another will give a similar machine the more pretentious designation of, say, the 'Albert' Pumping Engine. We are afraid that a satisfactory answer cannot be given to the question, but engineers appear to apply the term to any compact machine, vertical or horizontal, for pumping water (or other liquid) in which the power of the steam is applied directly to a plunger or piston (one or more) moving in a water-cylinder or water-cylinders, and the steam and water parts are either on a common bed-plate or foundation, or are otherwise so immediately and closely connected as to form, as it were, one machine. The term is not entirely restricted to single-cylinder engines; but in the case of a combination of steam-cylinders the engines are known as Com-

pound Steam-Pumps, in contradistinction to the Simple Pumps. By many engineers the term appears only to be applied to the single-cylinder engines; the compound pumps, from their greater size and importance, taking rank with other and more extensive forms of machinery, and for which the term 'steam-pump' is an insignificant designation.

Any steam-pumping machinery may be called a 'steam-pump.' The Cornish Engine, with its Pitwork, may be called a 'steam-pump:' that is, the pump or pumps in the shaft are moved by the agency of steam. But if we accept the foregoing definition, the Cornish Engine and Pitwork cannot be thus designated—firstly, because it is not direct-acting; secondly, because it is not compact; and thirdly, because the steam and water parts are not so closely connected as to form one machine. The Bull Engine and Pitwork, although direct-acting, cannot be considered a steam-pump in the sense of the foregoing definition. With this, as with the Cornish Engine, the pumping part is an adjunct, but in steam-pumps the pumping part is a component of the machine. True, the Cornish and Bull engines are not complete without the pumps, but it is not an absolute necessity that either of these engines should be used with the pumps. Other forms of engines, and even water and wind power, may be and are applied to work the pumps.

An order to a maker for a steam-pump would mean a machine with the steam and water parts complete, without, of course, the pipes, but if a Cornish Pumping Engine be ordered, only the steam-engine would be produced; the pumping parts would be quite a distinct matter, and might be had from another maker. The Pulsometer—than which no form of pumping machinery can be more literally a steam-pump in the principle of its action—is quite a different machine from the older and more extensively useful classes of pumps which form the subject of the present and following articles, and has only a very limited application.

HISTORY

The Direct-Acting Steam-Pump is distinctly a child of American birth and parentage, and its genesis must be studied chiefly in the life and career of that celebrated engineer, the late Henry Rossiter Worthington, of New York.

Other American engineers, notably Lucius J. Knowles of Warren, Massachusetts, George F. Blake of Boston, in the same State, and Adam Scott Cameron of New York, have distinguished themselves in the arena of pump invention, but to Worthington belongs the pre-eminent honour of priority of conception and design, the little boiler-feeder he patented in the year 1844 being the pioneer and prototype of all the engines of the non-rotary direct-acting class. His history of the Worthington pump is a record of achievements of which any engineer in this or any other age might justly be proud.

'The history of the "Direct-Acting Steam-Pump" differs from all others from the fact that it was the invention of one man, and was in the main perfected during his lifetime. It was so strikingly different from all that had preceded it, that there was nothing in the way of precedent, either in ancient or modern practice, of which the inventor could avail himself by which to aid or guide him to success.'

'About the year 1840 Worthington, then a young man of twenty-three, the son of a New York merchant, with no special training in the direction of mechanics, and with no opportunities beyond those which come to any young man eager to learn, and with no incentive beyond the love of a profession he afterwards lived to adorn, conceived the idea of applying the then somewhat newly discovered use of steam to the propulsion of canal boats.'[1]

In the course of his experiments with a steamboat designed for canal navigation, he observed the extent to which a hand-pump was used for keeping up the boiler supply, and sought to devise a labour-saving method. The result was the independent feeding-pump, patented September 7, 1844. It is shown in fig. 1 as attached to a boiler, and is a simple form of steam-pump, with a single-acting plunger and ordinary conical valves to the pump proper. The steam-cylinder is supplied with steam through a pipe, which has a valve at the other end within the boiler. This valve is controlled by a float, which, by its rising or falling, supplies more or less steam, and allows the pump to run faster or slower according to the height of the water.

The drawing shows a spring which acts upon the steam-valve. Its effect is thus described and claimed in the patent:—

'My improvement in the auxiliary engine consists in the manner of rendering the action of the slide valve certain, without its being necessary to depend upon the momentum of the engine therefor. The momentum is frequently insufficient for this purpose, and the valve is then liable to stop in such position as to cover both of the steam ports or openings into the steam cylinder. By my improvement the danger of the stopping of the valve in such a position as to prevent the motion of the engine is obviated.'[2]

Fig. 9 also represents this, the first, Worthington pump, truly 'a small affair, crude in its design, and rough and unsightly in its finish,' but interesting as being the first creation of Worthington's fertile brain, and prototype of the long series of pumps which have culminated in such splendid examples of direct-acting pumping engines as we find to-day in our mines and collieries. Worthington was not successful with his steam canal boat, but his experiments had this important and momentous result, that they led to the discovery of a new method of using steam for pumping water.

[1] J. F. Holloway: *Pumping Machinery, Ancient and Modern* (p. 9), a lecture delivered before the class of Mechanical Engineering of Sibley College, Cornell University, April 26, 1889.

[2] Henry R. Worthington: *The Worthington Steam Pumping Engine*, p. 4.

He writes: 'This, so far as I know, was the beginning of that numerous class of following inventions for storing power to act upon the steam valve when the momentum of the moving parts was insufficient to throw it through its full distance of travel. In the course of my experience I made

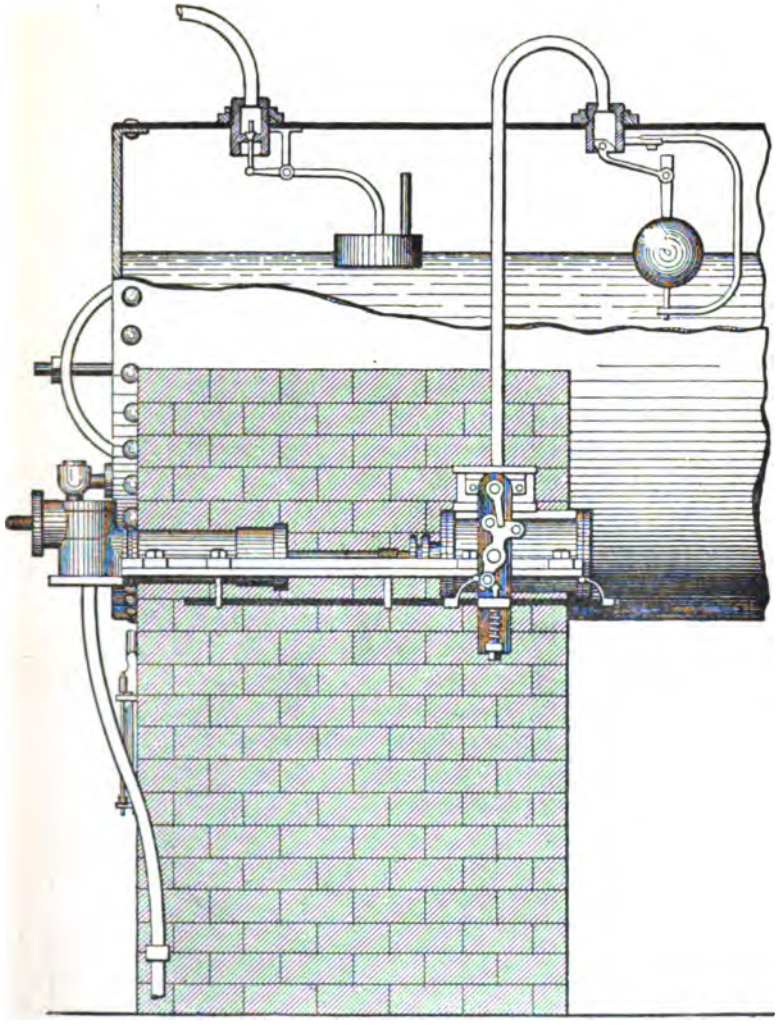


FIG. 1.—Worthington's Independent Feeding-Pump.

many arrangements for using the spring, other than that exhibited in the patent of 1844. One was the employment of a tube in place of the valve rod, with a spiral feather acted upon by an arm on the piston, which, in its motion back and forth, compressed the spiral spring within the tube (see

figs. 2 and 3). In this case the steam-valve, instead of working in line with the piston-rod, passed in a transverse direction over the openings.

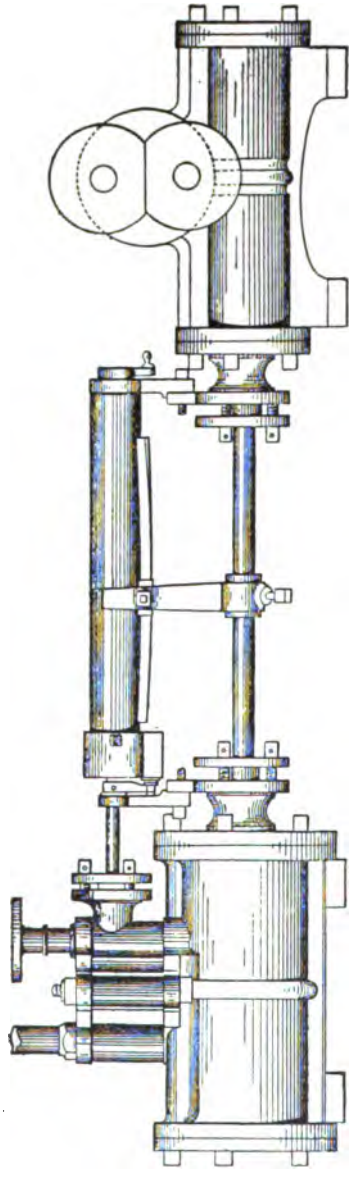


FIG. 2.—Worthington's Spring-Thrown Valve.

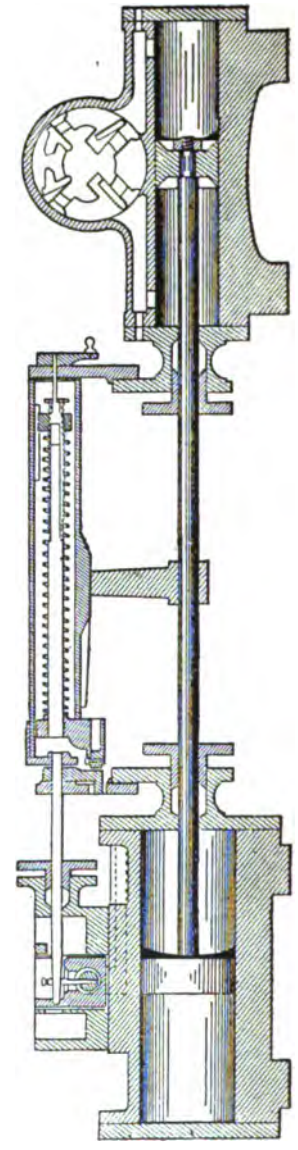


FIG. 3.—Worthington's Spring-Thrown Valve.

For the ordinary arrangements the B-valve, shown in fig. 4, was invented and used.'

'The step from this spring motion to the use of a small steam piston for driving the valve was obvious enough, and very soon made. The first and simplest arrangement is shown in fig. 5. They have since been

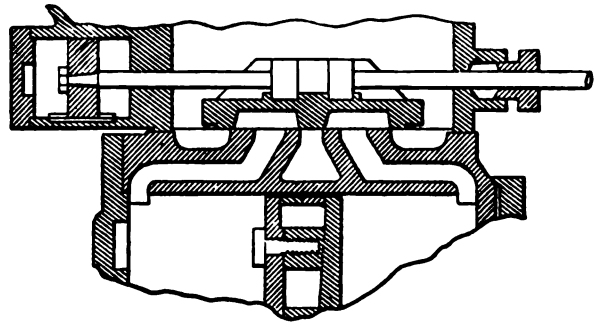


FIG. 4.—Worthington's B-Valve.

constructed in almost every conceivable way. In my first arrangement a rod protruded from the main steam-valve as well as from the auxiliary. The object of this was either to compel the full motion of the main steam-valve, or else the stoppage of the engine, in case the auxiliary piston failed

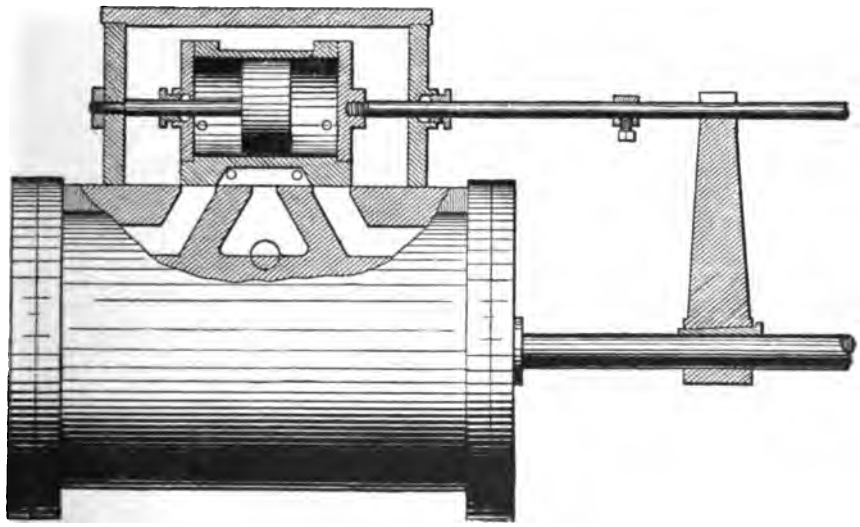
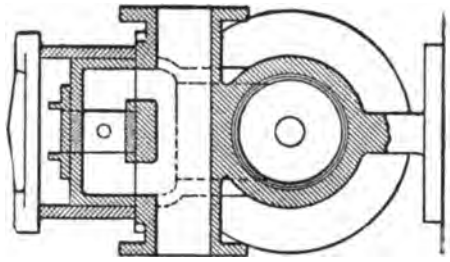


FIG. 5.—Worthington's Steam-Thrown Valve.

to work promptly. The auxiliary piston was acted upon by an auxiliary valve (not shown in cut) that was placed on the main piston valve, and was acted upon by a tappet arm through the medium of its own auxiliary valve rod.'



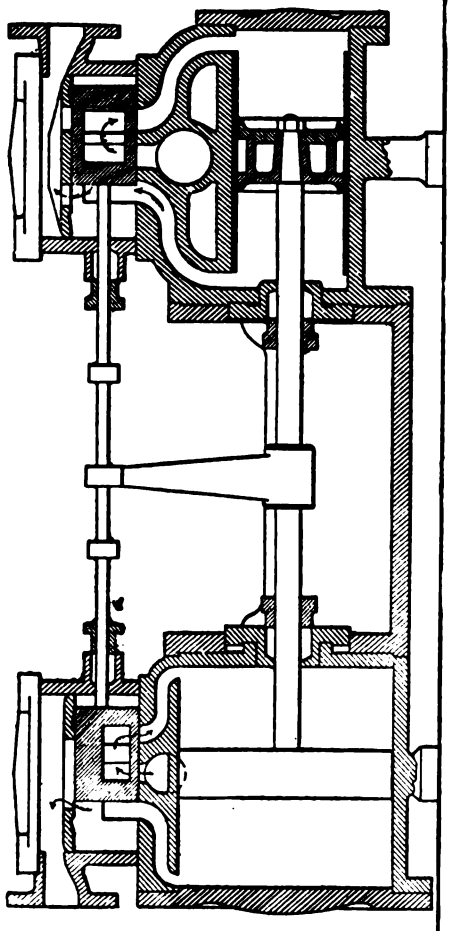


FIG. 6.—Worthington's Pump with Arbitrary Water-Valve Motion.

'An obvious difficulty resulted from the large size of piston required to handle an ordinary slide-valve. This suggested the balancing of the slide valve, which was accomplished . . . while retaining the general arrangement of the auxiliary piston.'

'In this balanced valve the direction of steam was changed, so as to have it enter at the exhaust port and escape into the steam chest, which was thus converted into an exhaust chest. Plates were fitted over the blocks, or check pieces at each end, thus forming a tight cavity or dash-pot, wherein the steam-valve would be brought up by the compression of steam within the cavity. A small valve was so arranged as to be opened at the prope time and destroy the tightness of the dash-pot, so that the valve could be withdrawn more readily. In the course of my protracted experience with auxiliary pistons, I adopted numerous arrangements not necessary to exhibit in this narration, involving numerous forms of steam, water, and air dash-pots for restraining their motion. I have still in my possession an old steam-pump used on the steamer "Bay State" for some years, commencing in 1849, and afterwards replaced by one of more modern form. I offer a sketch of it in fig. 6.

exhibiting an arbitrary water-valve motion, combined with the steam-valve, and moving simultaneously therewith. This, while operating as a water dash-pot to arrest the motion of the steam-valve, also made the

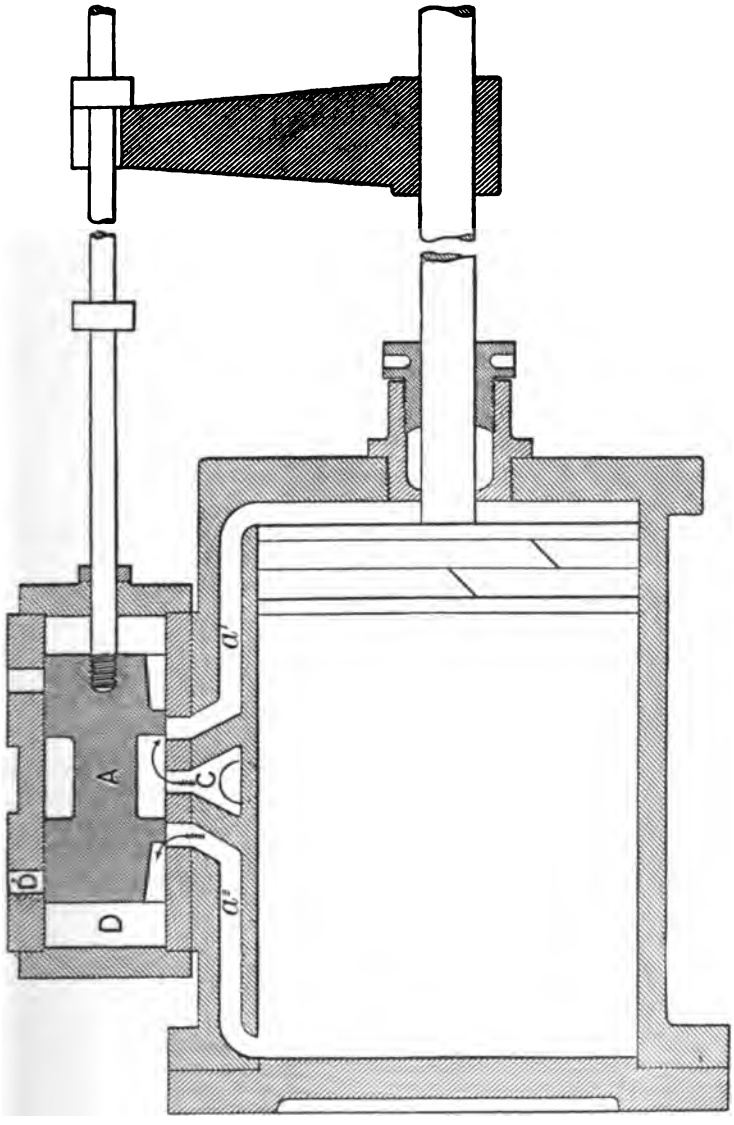


FIG. 7. - Worthington's Exhaust Valve-Throw.

movement of the pump-valve positive and certain. I have since adopted the same form of valve upon air-pumps, notably in the case of the war vessel " Dunderburg." . . .

'An interesting and efficient modification of the auxiliary-valve throw, and which I call the exhaust-valve throw, was made the subject of a patent in 1856. It is illustrated in fig. 7.

'The steam valve was constructed in the form of a piston working in a small cylinder constituting the steam chest, the steam being admitted at the centre and escaping at either end. A brief extract from the patent will fully explain this modification :—

'"As represented in the drawing, the main piston has just completed a stroke from left to right, the steam, admitted through the central opening C, is just on the point of passing to the right-hand end of the cylinder through the opening A 1, while the exhaust from the left-hand side, already commencing to escape through the port A 2, fills the space D, but from this space or cavity it has no escape until, by its elastic force, it crowds or forces the piston valve A towards the right, far enough to uncover the opening D 1, which communicates with the escape pipe or condenser. By this time the steam port A 1 of the main cylinder is also open for steam. Thus the necessary motion of the steam-valve is produced by the effort of the steam to escape from the small cylinder or valve chest so called."'[1]

Worthington's experiments in steam-valve mechanism, extending, up to this time, over a period of about ten years, appears to have been almost endless. He thus expresses his activity in this direction, as well as the disappointments he met with: 'I believe almost every change was rung upon a steam-valve throw, but in those days the amount of refinement and complication attending their construction and management seemed to be an insuperable bar to their rapid introduction. Upon the smallest provocation the use of a steam-pump would be abandoned and the old well-tried arrangements resumed; for no work was fitted up with reference to the exclusive use of a steam-pump—it was always secondary.'[2]

He met with discouragements in every direction; a great authority (James P. Allaire) 'nearly reduced me to hopeless inaction, by saying he considered it his duty to tell me that I was trying to invent a machine that was not wanted; that no part of the machinery, either of steamboats or for factory purposes, was more satisfactory and complete than that for pumping. And this appeared to be the opinion of almost every engineer.'[3] These rebuffs were sufficiently discouraging at the time, but were of great value in compelling Worthington to look still further He was then working with Wm. H. Baker as a partner, and they set themselves 'to achieve the desideratum of a direct-acting steam-pump with a simple ordinary slide-valve.'[4] This task was at last accomplished in the invention of what was called the 'relief-valve motion,' and was patented April 3, 1849, in the names of H. R. Worthington and Wm. H. Baker. 'From its discovery may date the real introduction and popularity of a class of machines which now covers the length and breadth of the land.'[5]

[1] Henry R. Worthington: *The Worthington Pumping Engine*, pp. 7-10.
[2], [3], [4], [5] *Ibid.* p. 14.

'Fig. 8 represents the original arrangement as presented at the Patent Office, combined with a pump fitted with radial water valves, and of which

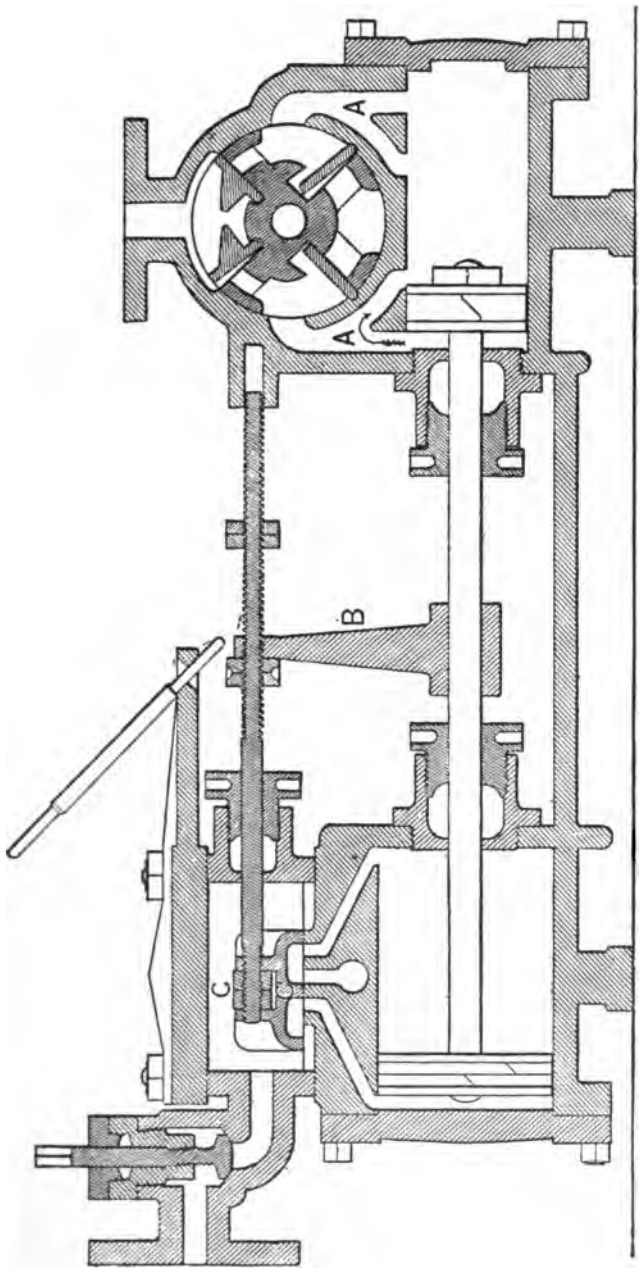


FIG. 8.—Worthington's Pump with Relief-Valve Motion.

there have been numerous modifications, still preserving the characteristic of relief. In this arrangement the momentum and expansion of the steam are made to conspire to carry the valve through its full distance in the following manner:—

'Two openings may be made into each end of the cylinder, coming together in one, as seen in the drawing at A A. When the piston moving from right to left arrives, as shown, nearly at the end of the stroke, the resistance is suddenly reduced, for the reason that the piston passes between the two openings and allows the fluid pressed before it to pass, with little or no obstruction, behind it in the direction of the arrow. The resistance being thus suddenly relieved, the momentum of the moving part, and the expansion of the steam in the cylinder acting through the arm B, serve to push the steam-valve C with quickness and certainty entirely over the opening. Several ways of thus relieving the resistance will occur to a mechanic. For example, the cutting of longitudinal grooves or recesses in the pump cylinder over which the piston may pass, or connecting the two ends of the pump chamber together by a pipe, in which a cock shall be opened and shut at the proper time by the motion of the engine; or a valve may be put in the piston itself; or when the water-valves are so constructed as to be moved by the machine in an arbitrary manner, independent of gravity, this valve may be so made as to allow the water to pass around it. The claim is for thus reducing or removing the resistance and operating the steam-valve.'[1]

A subsequent patent was granted, July 31, 1855, for a particular method of securing this effect, the claim being restricted to the described mode. Steam-pumps on this principle were extensively introduced and met with much favour. Fig. 10 is an illustration of the first improvement (1849) on the original Worthington pump.

In the year 1850, Worthington adopted, in a pump used on board the steamer 'Washington,' small india-rubber valves instead of a large valve with its high lift. These were rubber discs working upon a central stem over a series of half-inch holes, with a lift of not over a quarter of an inch. This appears to have been the first application of multiple valves.

Incidentally we may remark that Worthington's first waterworks engine was built for the city of Savannah, Georgia, and erected in 1854. The valve was thrown by relief motion, and the compound cylinders were annular in their arrangements.

There were other triumphs awaiting Worthington. He was not yet satisfied with his engine; he had marked the objectionable features of the single-acting pump as a pumping appliance for large quantities of water and high lifts. The action of the pump-plunger or piston was an intermittent one, the column of water coming to a stand at the end of each stroke, and having to be set in motion again with the next stroke; the flow of the water was thus irregular, and the pump and pipes and their joints were subjected to severe jolts and strains. Much time and intense

[1] Henry R. Worthington: *The Worthington Pumping Engine*, pp. 14–16.

study were devoted to the subject between the years 1859 and 1863, and in the last-named year he 'brought out at Charlestown, Massachusetts, his crowning success, the Duplex Engine, which fairly deserves to be placed first among the hydraulic inventions of this century.'[1] The name 'Worth-

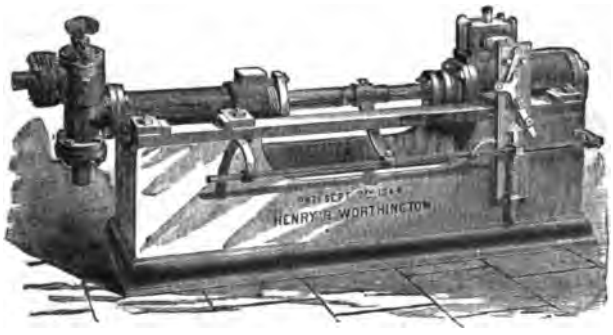


FIG. 9.—Worthington's First Pump (patented Sept. 7, 1844).

ington Direct-Acting Duplex Steam-Pump,' or, more briefly, the 'Worthington Duplex Pump,' was given to this construction early in the history of the invention, and it has ever since been commonly known by it. But this designation having been afterwards adopted for pumping machinery of

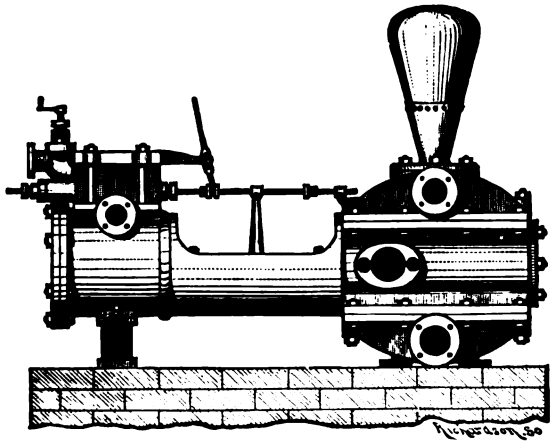


FIG. 10.—Worthington's Improved Pump (1849).

various kinds, it was abandoned by the makers, and the name 'Worthington Pumping Engine,' or 'Worthington Steam-Pump,' was applied to it by the makers.

The leading characteristics of this engine are the dual arrangement of

[1] E. D. Lewitt, Junr., in a paper read before the Montreal Meeting of the British Association of Scientists.

engines and pumps and the steam-valve mechanism, whereby the piston-rod of one engine is made to drive the slide-valve of the other, instead of operating its own as in the single pump. As this engine will be fully described hereafter, a brief outline of its construction must now suffice.

Two pumps of precisely similar construction are laid down side by side, each with its proper steam and exhaust valves, its piston and piston rod, and pump-plunger attached to the piston rod. 'In operation, one engine, while in full action, moves the valves of the other, when the piston of the latter gradually begins to move, and finally attains full velocity, as that of the first is checked by the steam cushion, and gradually comes to rest, the pump valves meantime seating quietly. The first engine pauses a moment till the second engine admits steam, when it commences a return stroke, and the second comes to rest—the action of one blending into that of the other as each alternately takes up the load—the result being that the discharge is constant and even, a uniform pressure is maintained in the main, and the pumps, under heavy or light pressure, operate without jar or noise.'[1]

When Worthington's lifelong labours came to an end his engine had been brought to a high state of excellence as a mining and general pumping agent, but for waterworks and other purposes, where large volumes of water have to be dealt with, it would not compare favourably with the large engines of other makers, particularly the 'Cornish' engines, and engines of the crank and fly-wheel type. Expansion by means of compound cylinders had been carried in this engine to its practical economic limit. The desideratum of a higher attainable limit of expansion, without sacrificing those distinguishing characteristics and advantages that had given the engine its reputation, was reached by C. C. Worthington, son of the great inventor. The 'High Duty Attachment' was a splendid conception, and marks a most important and radical advance in the position and history of the direct-acting engine. Fig. 11 is a sectional view of the Worthington Pumping Engine with the High Duty Attachment. As this engine is specially designed for waterworks and other heavy pumping at surface, we must content ourselves with a brief outline of the ingenious device named.

'The attachment consists, briefly, of two small oscillating cylinders attached to an extension of the plunger rod of the engine, preferably beyond the water end. These cylinders and their connecting pipes are filled with water or other liquid, and connected, either directly or through the medium of an accumulator, with the water in the force main of the pump. By this means a pressure on the pistons in these cylinders is maintained exactly equal to, or in proportion to, that in the force main. These pistons act in such a way with respect to the motion of the engine as to resist its advance at the commencement of the stroke, and assist it at the

[1] Henry R. Worthington: *The Worthington Steam Pumping Engine*, p. 45.

end; the water in the force main meanwhile exerting upon them a constant pressure at each point of the stroke.'

'The two cylinders act in concert, and, being placed directly opposite

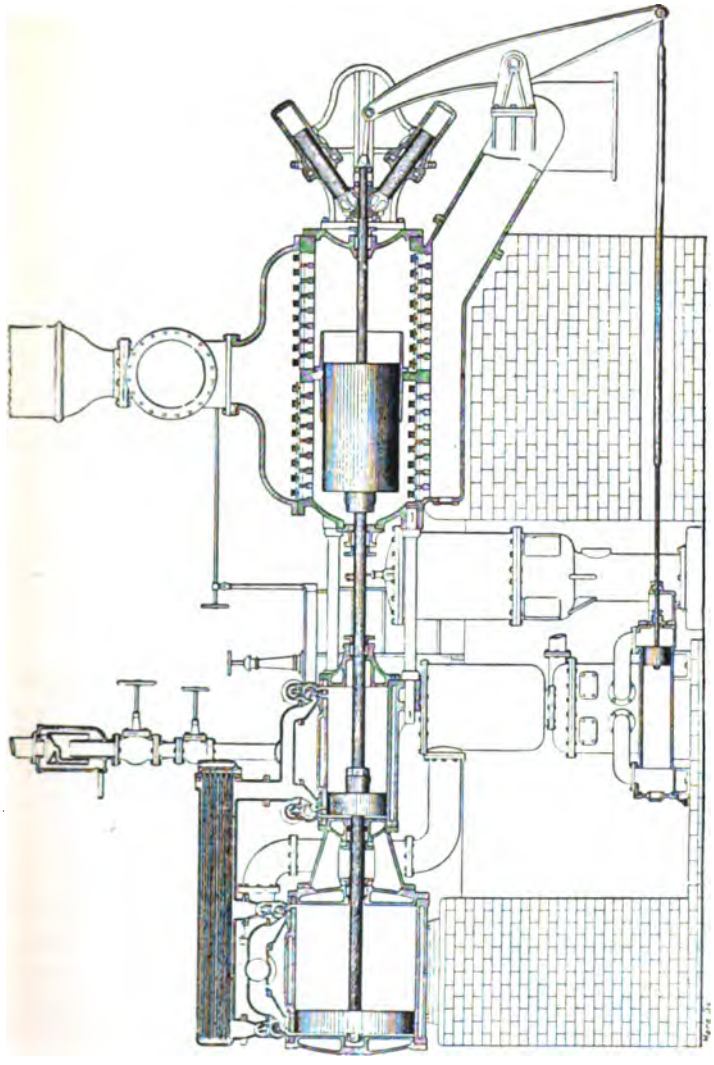


FIG. 11.—The Worthington Pump, with High Duty Attachment.

each other, relieve the crosshead to which they are attached of any sliding frictional resistance, and the engine of any lateral strain.'

'By alternately taking up and exerting power through the difference in the angle at which their force is applied with respect to the line of motion of the plunger rod, these two cylinders in effect perform the functions of a

fly-wheel, but with the important mechanical difference that they utilise the pressure in the force main instead of the energy of momentum. Whatever pressure is in the force main is directly communicated to the compensating cylinders, and any variation in the force main pressure is followed instantly by a corresponding variation in the cylinder pressure. Thus a uniform relation is maintained between the load on the pump plungers and the work performed by the compensators.'

'Their action is readily controlled, and their power is automatically proportioned to the work to be overcome, and is entirely unaffected by the speed of the engine. The same amount of expansion can be obtained in the same engine whether running at a piston speed of ten feet per minute or at one hundred and fifty. This latter feature is one of great importance, affecting, as it does so favourably, the economy of the engine when applied on any service where the demand is irregular or intermittent.'[1]

Furnished with this 'High Duty Attachment' and with triplication of the steam-cylinders, this engine, known as the 'Worthington High Duty Engine,' has passed to the front rank of economical waterworks engines. Being a comparatively recent invention we have disturbed chronological sequence in introducing it at this point, but have done so for the sake of presenting an unbroken record of the origin and successive developments of the Worthington engine under the creative brain and moulding hand of father and son.

A few years before Worthington conceived the idea of a Duplex Engine, Lucius J. Knowles, of Warren, Massachusetts, was busy on the famous pump that bears his name, his first patent being dated January 4, 1859. Knowles began life as a photographer, from which a natural gift for mechanics quickly diverted him. His first introduction to business was in association with Mr. S. H. Sibley, in the manufacture of cotton warps. Limited means compelling close attention to economy in every way, the question of fuel and steam consumption in their works was an important one. The exigencies of boiler feeding, as in the case of Worthington, first turned his attention to pumps, and demonstrated that here too 'necessity is the mother of invention.' He saw that a uniform and level supply of water in the boiler would conduce to economy, and to secure this without the expense of a man to watch the feed water he invented his automatic boiler-feeder. Increasing business made night work necessary, and to avoid the cost of a night engineer some kind of a boiler feed pump was required which could be operated by the automatic feeder referred to, and be positive in its action in order to keep the boilers supplied. The result was the invention of his first direct-acting single pump. Its action was so satisfactory, and elicited so much attention from engineers, that its manufacture for the market was soon commenced by the firm of Knowles

[1] *The Worthington Steam Pumping Engine*, pp. 136–138. [The later portion of this pamphlet was written after Worthington's death by his Firm.]

and Sibley. Successive improvements were made by the inventor, and the perfected engine of to-day stands in the very first rank of pumping appliances, and has achieved in the leading mining camps of the world an honourable distinction.

Knowles was quickly followed by another eminent American engineer, George F. Blake, of Boston, Massachusetts, who three years later designed the popular Blake pump, the drawing of the first pump bearing the date 1862; the first patent is dated April 12, 1864. He made many devices of this single-cylinder steam-pump, many of the earlier pumps being still extant and running apparently as well as any of the more modern types The pump as made to-day is entirely different from that first invented.

It is interesting to observe that Blake's first efforts were given to the construction of brick-making machinery. It was whilst thus engaged that he designed a duplex water meter, upon which he obtained three patents, dated April 1, March 25, and September 12, 1865.

Adam Scott Cameron, another American engineering genius, introduced in the year 1865 a pump which, under the name of the 'Special,' has won world-wide popularity. The inventor did well two years later in bringing his pump to England, and introducing it to Messrs. Tangye Brothers, of Birmingham, now Tangyes, Limited. The American congener, by the same inventor, and known as the Cameron pump, is manufactured by the A. S. Cameron Steam Pump Co., New York.

Another well-known pump of American origin is the 'Universal,' the invention of Ezra Cope and James Riley Maxwell, of Cincinnati; it was patented in England, September 15, 1868.

English engineers were later in the field with this class of pumps; but in 1850 William Elliot Carrett, of Leeds, designed a vertical fly-wheel engine with a lift and force pump combined. It was registered August 31, 1850.[1] Three years later the admirable vertical fly-wheel pump, known as the Cameron pump, was invented by John Cameron, of the Oldfield Road Iron Works, Salford, Manchester. Since its introduction it has been greatly improved. Pumps of the horizontal rotary class have also been designed by Mr. Cameron.

About the year 1865 Gilbert Lewis, of Manchester, patented a pump of the horizontal non-rotary class.

The years 1872, 1873, and 1874 witnessed considerable activity in pump construction, the 'Selden,' 'Imperial' (patented by J. E. Rogers),

[1] 'A steam-pump, combining a high-pressure engine and an improved suction and force-pump, designed and constructed for filling low or high-pressure locomotive, stationary, or marine steam-boilers, and for fetching or forcing water any distance or height; it may, by disconnecting the pump, be used as a steam engine for driving portable machinery for engineering works, the household or farmyard, for working hydraulic presses, water-cranes, &c. . . . It is constructed to fetch or force water any required distance *in one continuous stream*, without shock or injury to the pipes or machinery, and at an effective velocity. Mr. William Elliot Carrett, 13 Rockingham Street, Leeds, inventor and patentee.'—*Official Descriptive and Illustrated Catalogue of the Great Exhibition of* 1851, vol. i. p. 214.

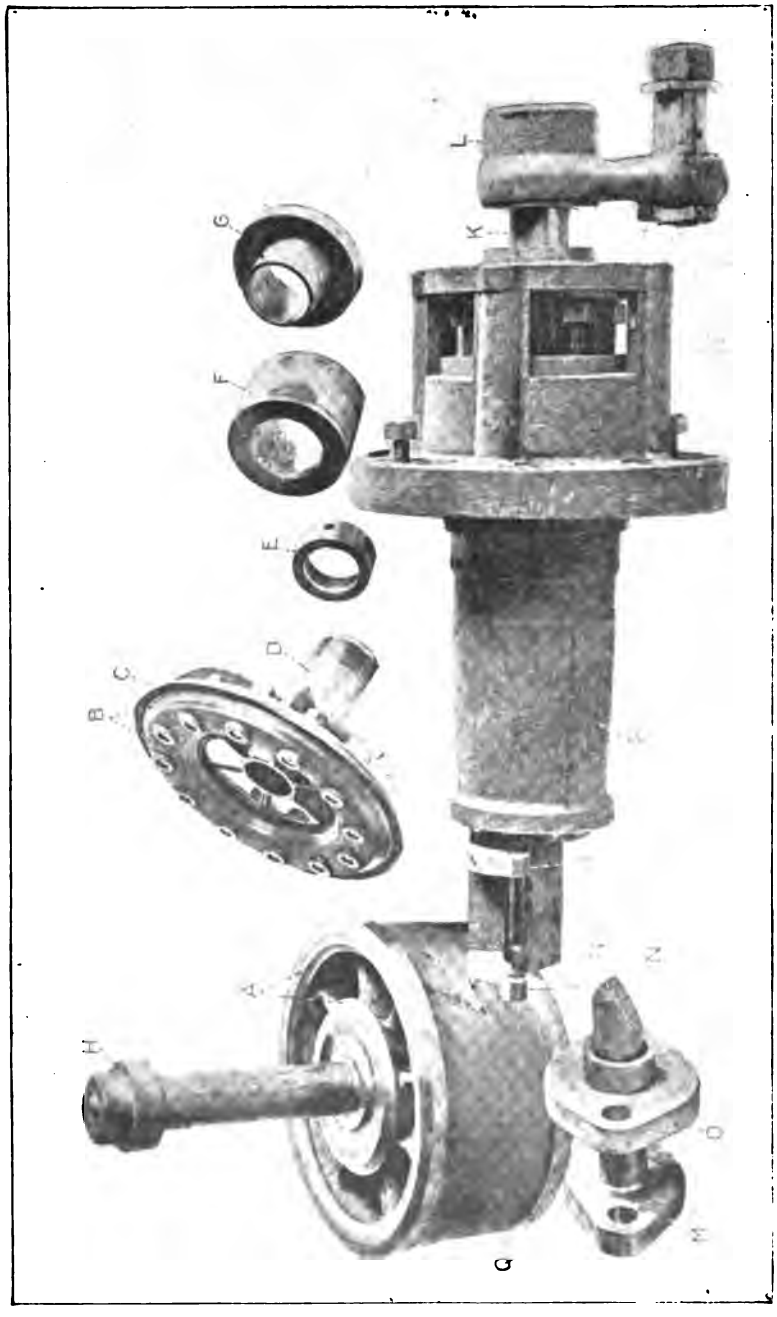


FIG. 12.—Riedler Pump-Valve Parts detached.

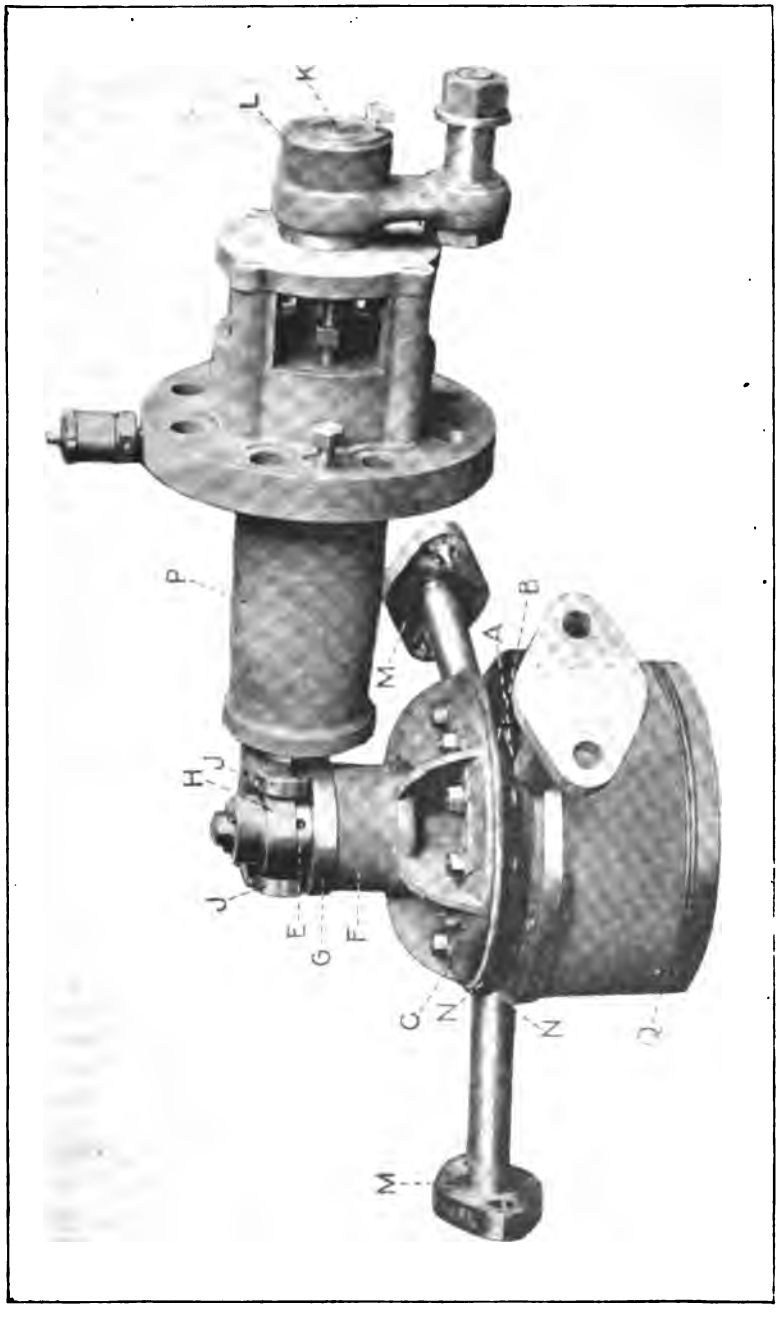


FIG. 13.—Riedler Pump-Valve Parts assembled.

'Standard, 'Caledonia,' and 'Colebrook'—all non-rotary pumps, amongst others, making their appearance. The last-named was patented by Cemer T. Colebrook, of London, March 25, 1874. These pumps differ one from another principally in the steam-valve gear, the inventions not being so much any new form of pump as some new idea embodied in the design for manipulating the motive power. A similar observation applies to the invention of Henry Davey, of Leeds, now of London, the well-known engineer, whose 'Differential' valve gear, introduced in 1874, has achieved such a conspicuous success in those engines to which it has been applied, and Mr. R. L. Howard, of London, whose design was patented March 13, 1877.

The 'Davidson' pump, of which frequent mention is made in these pages, is the invention of M. T. Davidson, of New York.

Pulsating pumps, a revival of Savery's idea of two centuries ago, have been in use nearly thirty years, the pioneer being the 'Pulsometer,' designed by C. H. Hall, an American, and patented September 24, 1872.

The next noteworthy achievement in the domain of pump construction is the invention in the year 1884, by Alois Riedler, Professor of Engineering at the Hochschule, Berlin, of the pump that bears his name, the salient feature of which is its mechanically operated water-valves.

Professor Riedler spent several years in the study of the principles of valve construction and action, and in investigating the laws affecting the passage of water through pipes and its action in pumping appliances. As a result he was enabled, after careful and protracted study and experiments, to design a pump which should in its construction and action be conformable thereto. His aim was to give free waterway through the valves and prevent loss by slip. This has been practically achieved by mechanically and automatically closing the valve immediately the pump stroke terminates. This is effected by an eccentric and lever operated by the pump. The following is a description, the illustrations (figs. 12 and 13) showing the details of a valve made for the large pump built for the Chapin Mining Co. On the left is the valve seat with its face marked 'A,' the spindle of same terminating with a cap (marked 'H'). Next is the valve proper, with its surface marked 'B.' The shank of valve is marked 'D,' through which passes the stem. 'F' is a rubber buffer fitting over shank of 'G,' which in turn fits over valve shank 'D,' and is prevented from slipping off same by cap nut 'E.' That portion of valve bonnet extending into valve chamber is marked 'P.' This bonnet contains the packing, through which extends the spindle 'K,' having on its end the forks 'J.' Keyed to the spindle 'K' is lever 'L,' through which the spindle receives its motion from the pump wrist plate. The bronze pins 'M' have taper ends which bear on the taper on edge of valve seat, and hold the valve seat down in position. The pins are forced in from the outside, thus obviating the necessity of work on the inside of pump body should it be necessary to remove the valve and seat. The glands 'O' prevent any leakage around the pins 'M.' Groove 'Q' is used for hydraulic packing.

Fig. 13 shows the different parts in their relative position for operation. This particular valve was built for a pump, the capacity of which is 2,200 gallons per minute against a head of 1,700 ft., which corresponds to a pressure of about 735 lbs. per square inch.

The latest additions to direct-acting steam-pumps appear to be the 'D'Auria' Pump, the invention of Luigi d'Auria, of the D'Auria Pumping Co., Philadelphia, and the 'Tipton' Compound Pump. The former is a modification of the Worthington Pump, as far as relates to the compensating principle of water-cylinders for storing up power at the beginning of the stroke and dispensing it at the end thereof. In the 'D'Auria' Pump this 'storing and restoring of the surplus energy of the steam exerted during the first half of the stroke over that necessary to overcome the resistance of the plunger is accomplished by what is termed a "water-governor," which is simply a closed loop or pipe filled with water, the ends of which pipe enter the two ends of the water-cylinder (located between the steam and the pump-cylinders), in which cylinder a plunger attached to the piston-rod is driven to and fro at each stroke of the pump. . . . With one of the experimental pumps, built by Mr. d'Auria, 12 in. diameter by 12 in. stroke, a speed of 180 ft. piston speed per minute has been obtained, and a duty of 35,000,000 foot-lbs. per 100 lbs. of coal, which is from two to three times the duty which might be expected of an ordinary direct-acting non-condensing pump of the same size.' [1]

The 'Tipton' Compound Pump was patented by Edmund Howl, of Dudley, and Walter Watkins Attwood, of Kidderminster, December 28, 1897. The salient features are the position of the steam-chest and ports, which make the engine self-draining, and working the high and low-pressure pistons in one cylinder. The same engineers have designed a single-cylinder engine in which the steam-chest is attached to the side of the main-cylinder.

CLASSIFICATION OF ENGINES

I. Horizontal Pumping Engines

A. *Rotary.*	B. *Non-Rotary.*
A. Simple Steam-Pumps.	A. Simple Steam-Pumps.
B. Compound Steam-Pumps.	B. Compound Steam-Pumps.
C. Riedler Steam-Pumps.	C. Triple Expansion Steam-Pumps.
	D. Sinking Steam-Pumps.

II. Vertical Pumping Engines.

A. *Rotary.*	B. *Non-Rotary.*
A. Simple Steam-Pumps.	A. Simple Steam-Pumps.
B. Compound Steam-Pumps.	B. Compound Steam-Pumps.
	C. Sinking Steam-Pumps.

III. Pulsating Pumping Engines.

[1] *The Mechanical Engineer*, May 7, 1898, p. 525.

A large variety of engines is comprised in the groups mentioned, engines of diverse types both as regards their steam distribution and their hydraulic arrangements. The following detailed classification attests the wonderful activity of inventive genius of the Victorian era in the production of direct-acting pumping engines. We have described and illustrated a great number of them, and generally in the order given. It would be easy to add both to the list and the illustrations, but no good purpose would be served by multiplying examples.

To avoid carrying classification to an extreme degree of attenuation we have (in those classes where the engines *as a whole* are of practically similar construction, yet considered *in detail* present points of divergence of a more or less marked character) indicated by a numeral after the maker's name the number of varieties and the engines belonging to each. In Horizontal Engines, group B, class A, section 1, the order of the engines is based on the steam arrangements, and section 2 on the hydraulic arrangements; class B, sections 2 and 4, are also grouped according to the hydraulic arrangements.

A difficulty presented itself in describing the various types of simple engines as *non-condensing*, as the whole of them may be, and in many instances are, made *condensing*; but, as in the great majority of cases they are not provided with condensers except in the larger sizes, and then only occasionally, it has been deemed advisable to cast the classification in a form that would best indicate their general characteristics. Their chief passport to favour is their relative small size, compactness, cheapness, and general handiness, which would be seriously prejudiced by the introduction of condensing arrangements. We do not refer, of course, to the small condensers sometimes attached to the suction pipe for the purpose of disposing of the exhaust steam; these are not employed for, nor are they suitable to, economy of working, but to get rid of a nuisance. The vacuum obtained by their use being extremely small, very little economy is realised. Nothing is to be inferred by the reader of the merits of the engines from the order in which they appear. Convenience of treatment, and the necessity of adopting a methodical and appropriate distribution of the engines according to their distinctive features, are alone responsible for the sequence of their appearance in these pages.

Many well-known pumps and manufacturers have not been named, simply because it has not been practicable, for several reasons, to include them, and not because they are not entitled to rank with any of those noticed. We believe that all the classes and types of underground direct-acting engines have been included, and in giving a few examples of leading pumps in each class the purpose of this little work is sufficiently attained.

CLASSIFICATION OF UNDERGROUND STEAM-PUMPING ENGINES.

I. Horizontal Pumping Engines.

A. Rotary Engines.

A. *Simple Steam-Pumps.*

1. Single steam-cylinder, expansive, non-condensing engines working double-acting piston-pump.

W. Turner	
W. H. Bailey & Co., Ltd.	The 'Cymric.'
„ „	The 'Merthyr.'
Jos. Evans & Sons	The 'Reliable.'

2. Single steam-cylinder, expansive, non-condensing engines working double-acting ram-pump.

John Cameron.	
Frank Pearn & Co., Ltd.	
Jos. Evans & Sons	The 'Reliable.'

3. Two steam-cylinder, expansive, non-condensing engines working double-acting ram-pumps.

Frank Pearn & Co., Ltd.

4. Three steam-cylinder, expansive, non-condensing engines, working double-acting ram-pumps.

R. Warner & Co.

B. *Compound Steam-Pumps.*

1. Compound steam-cylinder, expansive, condensing engines, working double-acting ram pump.

Frank Pearn & Co., Ltd.

C. *Riedler Steam-Pumps.*

B. Non-Rotary Engines.

A. *Simple Steam-Pumps.*

1. Single steam-cylinder, non-expansive, non-condensing engines working double-acting piston-pump.

Tangyes, Ltd. (1)	The 'Special.'
A. S. Cameron & Co., Ltd. (1)	The 'Cameron.'
Blake & Knowles Steam-Pump Works, Ltd. (2)	The 'Knowles.'
W. H. Bailey & Co., Ltd. (2)	The 'Davidson.'
Northey Manufacturing Co., Ltd. (2)	The 'Northey'

Blake & Knowles Steam-Pump Works, Ltd. (3)	The 'Blake.'
John H. Wilson & Co., Ltd. (3)	The 'Selden.'
Jos. Evans & Sons (4)	The 'Cornish.'
Lee, Howe & Co., Ltd.	The 'Tipton.'
Hayward-Tyler & Co. (5)	The 'Universal.'

2. Single steam-cylinder, non-expansive, non-condensing engines working double-acting ram-pump.

Hayward-Tyler & Co. (1)	The 'Universal.'
A.S.Cameron & Co.,Ltd. (2)	The 'Cameron.'
Jos. Evans & Sons (2)	The 'Cornish.'
John H. Wilson & Co., Ltd. (2)	The 'Selden.'
Hayward-Tyler & Co. (2)	The 'Niagara.'
Hathorn, Davey & Co. (2)	Davey's 'Differential.'
Hayward-Tyler & Co.	The 'Self-Governing.'
W. H. Bailey & Co., Ltd. (3)	The 'Davidson.'
Blake & Knowles Steam-Pump Works, Ltd. (3)	The 'Blake.'
Blake & Knowles Steam-Pump Works, Ltd. (3)	The 'Knowles.'
Tangyes, Ltd. (3)	The 'Special.'
Pulsometer Engineering Co. Ltd. (3)	The 'Deane.'

3. Two steam-cylinder, non-expansive, non-condensing engines working double-acting piston pumps.

Worthington Pumping Engine Co.	The 'Worthington.'
Northey Manufacturing Co. Ltd.	The 'Northey.'
Alex. Shanks & Co., Ltd.	
Tangyes, Ltd.	
W. H. Bailey & Co., Ltd.	
Hayward-Tyler & Co.	The 'Gordon.'
Pulsometer Engineering Co., Ltd.	The 'Deane.'

4. Two steam-cylinder, non-expansive, non-condensing engines working double-acting ram-pumps.

Worthington Pumping Engine Co. (1)	The 'Worthington.'
Blake & Knowles Steam-Pump Works, Ltd. (1)	The 'Blake.'

Blake & Knowles Steam Pump Works, Ltd. (1)	The 'Knowles.'
Northey Manufacturing Co. Ltd. (1)	
Worthington Pumping Engine Co. (2)	The 'Worthington' (Scranton Mine Pattern)
Frank Pearn & Co., Ltd. (2)	The 'Manchester.'
Jos. Evans & Sons (2)	The 'Cornish.'
Hayward-Tyler & Co. (2)	The 'Gordon.'
Tangyes, Ltd. (3)	
Frank Pearn & Co., Ltd. (3)	The 'Manchester.'
Blake & Knowles Steam-Pump Works, Ltd. (3)	The 'Knowles.'
Blake & Knowles Steam-Pump Works, Ltd. (3)	The 'Blake.'

5. Single steam-cylinder, expansive, condensing engines working double-acting ram-pump.

Hathorn, Davey & Co.	Davey's 'Differential.'
Hayward-Tyler & Co.	The 'Self-Governing.'

B. *Compound Steam-Pumps.*

1. Compound steam-cylinder, expansive, condensing engines working double-acting piston-pump.

Alex. Shanks & Co., Ltd.	
W. H. Bailey & Co., Ltd.	The 'Davidson.'
Jos. Evans & Sons	The 'Cornish.'

2. Compound steam-cylinder, expansive, condensing engines working double-acting ram-pump.

Hathorn, Davey & Co. (1)	Davey's 'Differential.'
Lee, Howe & Co., Ltd. (2)	The 'Tipton.'
W. H. Bailey & Co., Ltd. (2)	The 'Davidson.'
Pulsometer Engineering Co., Ltd. (2)	The 'Deane.'
Hayward-Tyler & Co.	
Tangyes, Ltd.	

3. Twin compound steam-cylinder, expansive, condensing engines working double-acting piston-pumps.

Hayward-Tyler & Co.	
Worthington Pumping Engine Co.	The 'Worthington.'
Frank Pearn & Co., Ltd.	
W. H. Bailey & Co., Ltd.	

Blake & Knowles Steam-Pump Works, Ltd. . The 'Knowles.'
Tangyes, Ltd.

4. Twin compound steam-cylinder, expansive, condensing engines working double-acting ram-pumps.

Worthington Pumping Engine Co. (1) . . . The 'Worthington.'
Worthington Pumping Engine Co. (2) . . . „
Hayward-Tyler & Co. (2)
Jos. Evans & Sons (2)
Tangyes, Ltd. (3)
Blake & Knowles Steam-Pump Works, Ltd. (3) . The 'Knowles.'
Blake & Knowles Steam-Pump Works, Ltd. (3) . The 'Blake.'
Frank Pearn & Co., Ltd.

C. *Triple Expansion Steam-Pumps.*

1. Triple steam-cylinder, expansive, condensing engines working double-acting piston-pumps.

W. H. Bailey & Co., Ltd. . The 'Davidson.'

2. Triple steam-cylinder, expansive, condensing engines working double-acting ram-pumps.

Frank Pearn & Co., Ltd.
W. H. Bailey & Co., Ltd. . The 'Davidson.'
Pulsometer Engineering Co., Ltd. . . . The 'Deane.'

3. Twin triple steam-cylinder, expansive, condensing engines working double-acting ram-pumps.

Frank Pearn & Co., Ltd.
Worthington Pumping Engine Co.
W. H. Bailey & Co., Ltd. . The 'Davidson.'
Pulsometer Engineering Co., Ltd. . . . The 'Deane.'

D. *Sinking Steam-Pumps.*

Tangyes, Limited . . The 'Special.

II. Vertical Pumping Engines.

A. Rotary Engines.

A. *Simple Steam-Pumps.*

1. Single steam-cylinder, expansive, non-condensing engines working double-acting piston-pump.

W. H. Bailey & Co., Ltd.

2. Single steam-cylinder, expansive, non-condensing engines working one single-acting ram-pump.

John Cameron.
Jos. Evans & Sons . . The 'Ram.'
Elijah Ashworth.
Frank Pearn & Co., Ltd. . The 'Cameron.'

3. Single steam-cylinder, expansive, non-condensing engines working two single-acting ram-pumps.

John Cameron.

4. Single steam-cylinder, expansive, non-condensing engines working one double-acting ram-pump.

Frank Pearn & Co., Ltd.
Elijah Ashworth . . The 'Simplex.'

5. Two steam-cylinder, expansive, non-condensing engines working two single-acting ram-pumps.

John Cameron.
Jos. Evans & Sons . . The 'Ram.'
Frank Pearn & Co., Ltd. . The 'Cameron.'
" " . The 'Manchester.'

6. Two steam-cylinder, expansive, non-condensing engines working two double-acting ram-pumps.

John Cameron.
Frank Pearn & Co., Ltd.
Elijah Ashworth . . The 'Simplex.'

B. *Compound Steam-Pumps.*

1. Compound steam-cylinder, expansive, condensing engines working double-acting ram-pump.

Frank Pearn & Co., Ltd.
John Cameron.

2. Twin compound steam-cylinder, expansive, condensing engines working double-acting ram-pumps.

Frank Pearn & Co., Ltd.
John Cameron.

B. NON-ROTARY ENGINES.

A. *Simple Steam-Pumps.*

1. Single steam-cylinder, non-expansive, non-condensing engines working double-acting piston-pump.

Tangyes, Ltd. . . . The 'Special.'
Jos. Evans & Sons . . The 'Cornish.'

W. H. Bailey & Co., Ltd.
Pulsometer Eng. Co., Ltd. The 'Deane.'

2. Two steam-cylinder, non-expansive, non-condensing engines working double-acting piston-pumps.

Alex. Shanks & Co., Ltd.
Frank Pearn & Co., Ltd. . The 'Manchester.'
Pulsometer Eng. Co., Ltd.

B. *Compound Steam-Pumps.*

1. Compound steam-cylinder, expansive, non-condensing engines working double-acting piston-pump.

W. H. Bailey & Co., Ltd.

2. Twin compound steam-cylinder, expansive, non-condensing engines working double-acting piston-pumps.

W. H. Bailey & Co., Ltd.

C. *Sinking Steam-Pumps.*

Tangyes, Ltd. . . .	The 'Special.'
Jos. Evans & Sons . .	The 'Cornish.'
" . .	"
Northey Manufacturing Co., Ltd.	
Blake & Knowles Steam-Pump Works, Ltd. .	The 'Blake.'
Blake & Knowles Steam-Pump Works, Ltd. . .	The 'Knowles.'
Blake & Knowles Steam-Pump Works, Ltd. . .	The 'Palmer.'
W. H. Bailey & Co., Ltd. .	The 'Denaby.'
Frank Pearn & Co., Ltd. .	(Duplex).
Hayward-Tyler & Co. .	The 'Gordon' "
Worthington Pumping Engine Co. . . .	The 'Worthington' "
Lee, Howl & Co., Ltd. .	The 'Tipton.'

III. PULSATING PUMPING ENGINES.

Pulsometer Eng. Co., Ltd.	The 'Pulsometer.'
W. H. Bailey & Co., Ltd. .	The 'Aqua-Thruster.'
Körting Brothers . .	The 'Pulsator.'
Jos. Evans & Sons . .	The 'Fluometer.'
Waterspout Engineering Co.	The 'Waterspout.'

I.

HORIZONTAL PUMPING ENGINES

A.—ROTARY HORIZONTAL ENGINES

OPINION is greatly, although it would seem not equally, divided with regard to the relative merits of rotary and non-rotary engines. Each class has its advocates, and makers are very emphatic in their claims to superior excellence for their respective engines.

Where such a diversity of opinions is expressed we must look elsewhere than to the academic discourses of the lecture hall and the pages of makers' catalogues, valuable and helpful as these may be, for a reliable assessment of the worth of such engines.

Many an engine that has been theoretically perfect, that has embodied the most correct principles of mechanics, and in the foundry has run splendidly, has in actual work demonstrated some inherent fault or weakness. The last and the decisive word must always come from the actual *users* of the pumps, hard matter-of-fact observant men who, down in the bowels of the earth, have handled them under all conceivable circumstances and conditions, and have, as it were, felt their very pulse and their hearts beat. It is here in a service that, in its heavy, rough, and exacting nature knows no parallel, and under conditions that have no counterpart, that the inherent qualities of a pump find their supremest test, and the high laudations of makers and the encomiums of savants are confirmed or confuted, and reputations are made or marred. For, after all that may be said and written, the arbitrament of experience, from which there can be no appeal, is the final pronouncement for the miner and the engineer.

From the fact that the *Rotary Principle* has not been largely adopted in mines and collieries for horizontal engines, and that the number of non-rotary engines greatly exceed the rotary, the inference that may be safely drawn is that the balance of advantage largely preponderates on the side of the former. Let us briefly consider why this is so.

More room is required, and as a rule the engines have more parts than the non-rotary engines. They are heavier, and consequently are less portable, and not so easily handled and fixed. They are more costly, more expensive to keep in order, require more attention, and are more liable to derangement. In cases where a valve sticks up or is broken or otherwise damaged, or the pump gets partially or wholly 'foot-fast,' the consequences to a rotary pump would be very serious, unless the derangement were quickly detected. If wholly 'foot-fast,' the engine, released from its load,

would work up to an alarming speed (in the absence of the engineer), and result in a breakdown. When a pump draws air, which is not an infrequent occurrence, the effects are more injurious in the case of a rotary than of a non-rotary engine. Moreover the pauseless continual motion of the rotary engine is not conducive to effective action of the pump-valves, which require a momentary pause at the end of the stroke.

'They (non-rotary pumps) are very popular on account of their cheapness, and certainly owing to their simplicity. In many cases they are inevitable, because they can be placed in places where the room is not nearly sufficient for pumping engines of other kinds.'[1]

'In the United States, underground pumps are mostly of the direct-acting type, although recently rotative Riedler pumps have come into use in a few places. The reason for the preference of the non-rotative pumps is due to their greater compactness, simplicity, cheapness in the case of smaller sizes, and minimum of attendance required; also because economy in the use of fuel, particularly in smaller plants, is generally of less importance than other considerations.'[2]

We must make an exception in favour of the Riedler pumps, which will be discussed in a separate chapter, and it must be understood that the foregoing remarks do not apply in their entirety to pumps arranged on this principle.

Turning now to the points of excellence of these pumps we may observe:—

They possess such important advantages over non-rotary pumps as greater economy of working and certainty of action. By using a heavy fly-wheel or wheels, great regularity in the strokes is obtained, and erratic movements are impossible; the piston may work to within a quarter of an inch of the covers without any risk of knocking them out, and it is almost impossible for the engine to become 'centred.' In pumps of the non-rotary class it is customary to leave a clearance of from one to three inches, to avoid injury to the covers.

It is claimed that these pumps are from thirty to fifty per cent. more economical than the non-rotary types. Power is stored up in the fly-wheel at the earlier part of the stroke, and is given out at the latter, enabling the steam to be used expansively, and to work with an economy that is impossible with non-fly-wheel pumps. Moreover, the stroke being continuous, there is a uniform and steady flow of water which largely contributes to economy of working, there being no inertia to overcome at the end of the stroke as in the non-rotary pumps. It is true that for the same size cylinders and length of stroke they occupy more space than the non-rotary pumps, but this disparity is reduced to some extent by the higher speeds at which they may be driven, admitting of their being made of smaller size for similar work. There is a variety of types of this

[1] C. M. Percy: *Mechanical Engineering of Collieries*, vol. ii. p. 156.
[2] Hans C. Behr: *Mine Drainage, Pumps, &c.*, p. 120.

engine—single, double, and triple steam-cylinders and compound steam-cylinders, working double-acting pistons, buckets, or rams, but they may be divided into two classes, namely, simple and compound.

A.—SIMPLE STEAM-PUMPS

Description.

These engines consist of one steam-cylinder with one or two fly-wheels, but generally two. Usually the fly-wheels are fixed behind the water part of the pump, one on each side, and work on the same crank-shaft, and they operate a pair of cranks, one of which is connected by means of a rod to one side of the ram or piston, as the case may be, and the other to the other side. In the former the ram works in two cases or working-pumps, thus forming two single-acting pumps, or one double-acting pump. The air-vessel is attached to a delivery-pipe, which is connected to the two delivery-branches. The steam-cylinder in these engines forms a somewhat insignificant factor at one end of the machine, being dwarfed by the fly-wheels. The steam-valves are of the ordinary slide-valve type, and are actuated by eccentrics on the crank-shaft. The fly-wheel acts as a regulator and a power reservoir, alternately accumulating and dispensing energy according to the angular position of the crank. The latter and the connecting-rods limit the stroke of the piston and enable the engine to be run close up to the cylinder-cover without risk.

Pumps of this type are useful for situations where there is not sufficient head-room for vertical pumps.

Owing to their weight and the room required, these pumps are not used for sinking operations.

There are several types of engines of this class with the details variously arranged as will presently be seen, but they may be resolved into two main divisions :—piston-pumps and ram-pumps, the examples we have observed giving the following subdivisions :

1. Single steam-cylinder and double-acting piston-pump.
2. Single steam-cylinder and double-acting ram-pump.
   Single steam-cylinder and double-acting ram-pump (two single-acting rams).
3. Two steam-cylinders and two double-acting ram-pumps.
4. Three steam-cylinders and three double-acting ram-pumps (three pairs of single-acting rams).

Sizes, Weights, and Speed.

Sizes.—These engines can be made of any capacity to suit the work to be performed. For engines of the same cylinder, area, and stroke, they occupy more room than the non-rotary engines. The following table gives the dimensions of the foundation-plate of various sizes of engines and the space they require. The actual space required for the engines is greater

than the measurements given of the foundation-plates, as the fly-wheels and steam-cylinders generally project beyond the plate. If we add one-third to the lengths given and one-fourth to the widths, we shall approach very nearly the actual area covered by the engines.

In the second table we have the exact over-all dimensions of Mr. John Cameron's Double-Ram Horizontal Pumps (see fig. 19), and other useful information.

Diameter of steam-cylinder	Diameter of pump	Stroke	Dimensions of foundation-plate	Space required
in.	in.	in.	ft. in. ft. in.	ft. in. ft. in.
4	2	4	3·2 × 1·1	4·3 × 2·3
4	2½	4	4·6 × 1·8	6·0 × 2·6
4	2½	5	4·6 × 1·8	6·0 × 2·6
6	3	6	4·6 × 1·8	6·0 × 2·6
7	3½	7	5·3 × 2·0	7·6 × 2·6
8	4	8	5·3 × 2·0	7·6 × 2·6
9	4½	9	6·0 × 2·3	9·6 × 3·0
10	5	10	6·0 × 2·3	9·6 × 3·0
12	6	12	8·9 × 3·0	12·0 × 3·0
10	5	15	—	13·0 × 3·0
12	6	18	—	15·0 × 4·0
14	7	21	—	16·0 × 4·0
18	9	24	—	20·0 × 5·0
30	12	28	—	22·0 × 6·0

Diameter of steam cylinder	Diameter of ram	Length of stroke	Revolutions per minute	Gallons per hour	Suction pipes	Delivery pipes	Steam pipes	Exhaust pipes	Total length	Width outside fly-wheels	Height to top of air vessel	Diameter of fly-wheels
in.	in.	in.			in.	in.	in.	in.	ft. in.	ft. in.	ft. in.	ft. in.
6	3	6	105	1,800	2½	2	2½	1	7 6	3 0	3 0	2 3
7	3½	7	94	2,560	2½	2	2½	1¼	8 3	3 1½	3 1½	2 6
8	4	8	90	3,580	3	2½	1	1¼	8 11	3 3	3 3	2 9
10	5	10	80	6,360	4	3	1¼	1½	10 1	3 5½	3 8½	3 0
12	6	12	70	9,660	4½	3½	1½	2	11 10	3 9½	4 4	3 9

Weights.—These engines are heavier than non-rotary engines of equal capacity, owing to the heavy fly-wheels. Compared with the last-mentioned pump in the following table, a 12-inch steam-cylinder engine of the non-rotary class, with an 8-inch pump and 12-inch stroke, weighs only 22 cwt., or about one-third of the engine named.

Dia. of steam-cylin.	Dia. of pump	Stroke	Weight	Dia. of steam-cylin.	Dia. of pump	Stroke	Weight
in.	in.	in.	tons cwt. qrs. lbs.	in.	in.	in.	tons. cwt. qrs. lbs.
4	2	4	0 2 0 0	8	4	8	0 14 0 0
4	2½	4	0 7 0 0	9	4½	9	1 2 0 0
4	2½	5	0 7 1 0	10	5	10	1 16 0 0
6	3	6	0 9 3 0	12	6	12	3 0 0 0
7	3½	7	0 12 0 0	—	—	—	—

The Cameron pumps enumerated in the second table of sizes weigh approximately 17, 23½, 30, 39, and 56 cwts. respectively. The fly-wheels and bed-plate can be made in halves for facility of transport down the shaft.

Speed.—The following tables give the speed and other particulars for moderate lifts of double ram-pumps. The second table refers to the Cameron engine (fig. 19).

Double Rams with Short Stroke.

Dia. of steam-cyl.	Dia. of pump	Stroke	Suction	Dely.	Steam	Exhaust	Feet per minute	No. of revol.	Gallons per hour
in.	in.	in.	in.	in.	in.	in.			
6	3	6	3	2½	1¼	1½	85	85	1,300
7	3½	7	3½	3	1¼	1½	93	80	1,900
8	4	8	4	3	1½	2	100	75	2,700
9	4½	9	4½	3½	1¾	2¼	105	70	3,600
10	5	10	5	4	2	2½	108	65	4,500
12	6	12	6	5	2½	3	120	60	7,200

Dia. of steam-cyl.	Dia. of pump	Stroke	Suction	Dely.	Steam	Exhaust	Feet per minute	No. of revol.	Gallons per hour
6	3	6	2½	2	¾	1	105	105	1,800
7	3½	7	2½	2	¾	1¼	110	94	2,560
8	4	8	3	2½	1	1½	120	90	3,580
10	5	10	4	3	1¼	1¾	133	80	6,360
12	6	12	4½	3½	1½	2	140	70	9,660

Double Rams with Long Stroke.

Dia. of steam-cyl.	Dia. of pump	Stroke	Suction	Dely.	Steam	Exhaust	Feet per minute	No. of revol.	Gallons per hour
in.	in.	in.	in.	in.	in.	in.			
8	4	12	4	3	1½	2	120	60	3,200
10	5	15	5	4	2	2½	125	50	5,200
12	6	18	6	5	2½	3	130	43	7,800
14	7	21	6	5½	3	3½	140	41	11,500
16	8	24	8	7	3	4	150	37	16,000
18	9	24	8	7	3½	4	150	37	20,300
20	10	28	9	8	3½	4½	160	34	27,000
24	12	28	10	9	4	5	160	34	38,400

Capabilities.

These pumps may be employed for general underground drainage of the light character performed by other steam-pumps. They are obviously not suitable for pumping out shafts, as they cannot easily be swung upon a movable frame. They occupy more room than other forms of pumps, and being comparatively very heavy it would not be an easy task to move a large engine as the water decreases. The fly-wheels are usually massive, and would be very much in the way in a shaft.

For use at the bottom of a shaft, or in a sump or gallery, where there is sufficient space, pumps of this type will be found to be very useful and less extravagant of fuel than simple non-rotary pumps.

The engines can be made to force to any height attainable by other steam-pumps. Engines of this class having 47-inch and 45-inch steam-cylinders, with 15-inch and 9-inch pumps respectively, and 3-feet stroke,

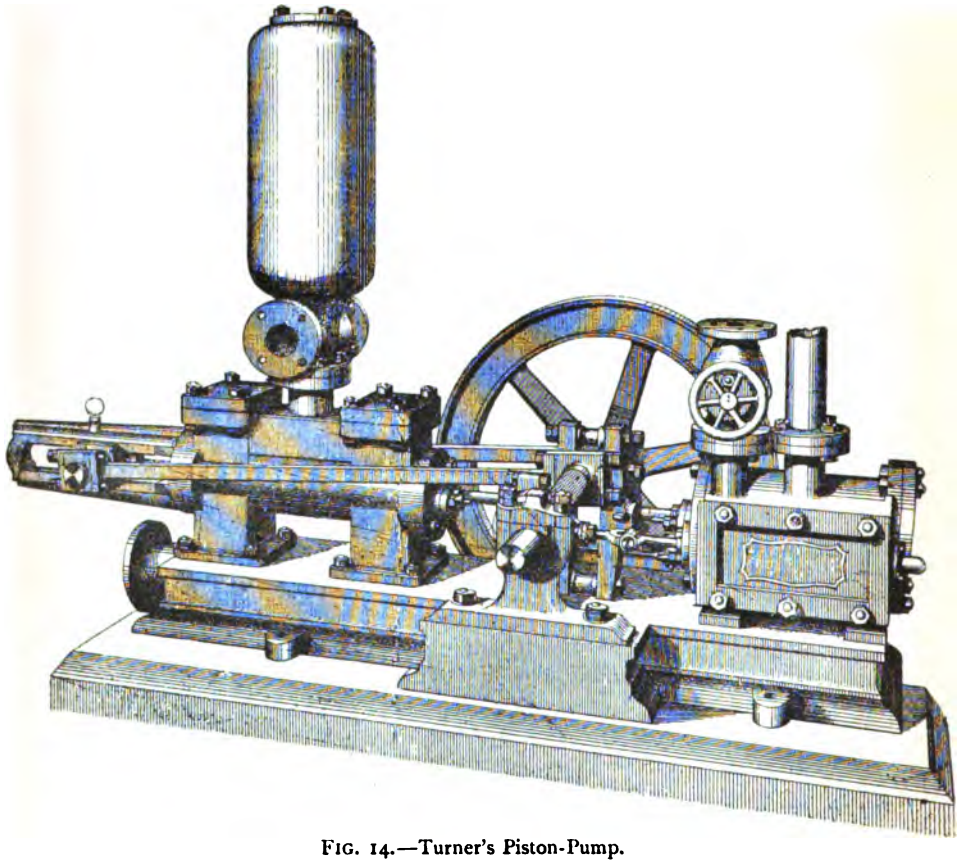


FIG. 14.—Turner's Piston-Pump.

working against a head of about 900 feet, have been made for the Zabreze and Königshutte mines in Germany.

Mr. John Cameron supplied in 1890 to Messrs. G. Insole and Son, Cardiff, a 33-inch steam-cylinder, 10-inch ram-pump with 20-inch stroke, with jet-condenser and governor, to deliver against a head of 450 feet 30,000 gallons per hour. The fly-wheels and bed-plate were made in halves for convenience in lowering down the pit. The same maker supplied, in February and November 1894, two pumps to Platt Brothers & Co.,

Oldham; the ram of the first was 3¼-inch diameter at one end and 3-inch at the other, in order to compensate for the space occupied by the piston-rod; the steam-cylinder was 10-inch diameter, with 8-inch stroke. It was worked by compressed air varying in pressure from 40 to 45 lbs. per square

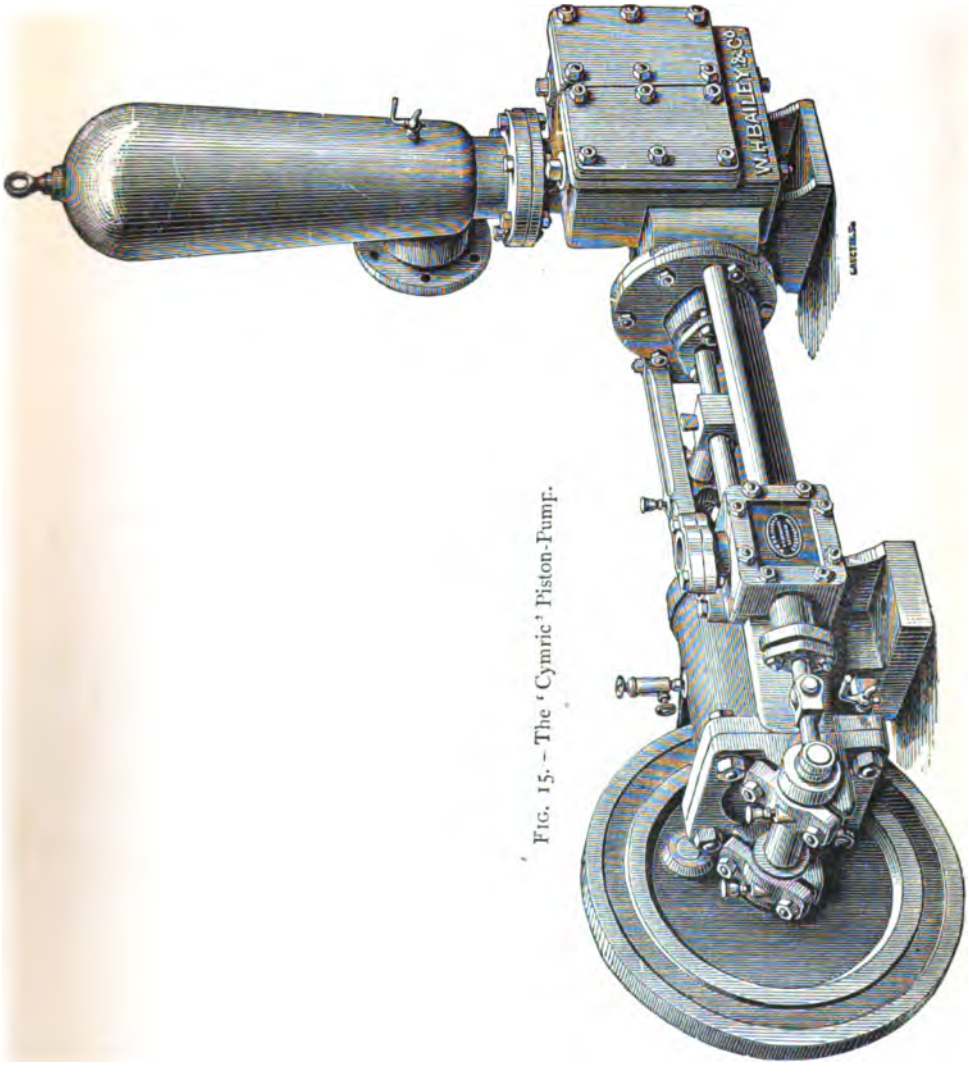


FIG. 15. – The 'Cymric' Piston-Pump.

inch, and pumped against a delivery head equal to 185 lbs. per square inch, the general speed being 38 revolutions per minute. The second pump was slightly larger, and worked under similar conditions. Both pumps were fitted with spindle valves having flat faces covered with leather.

Cost.

Rotary are more costly than non-rotary pumps. The difference in small sizes is about 15 per cent. and in large sizes about 25 per cent. The

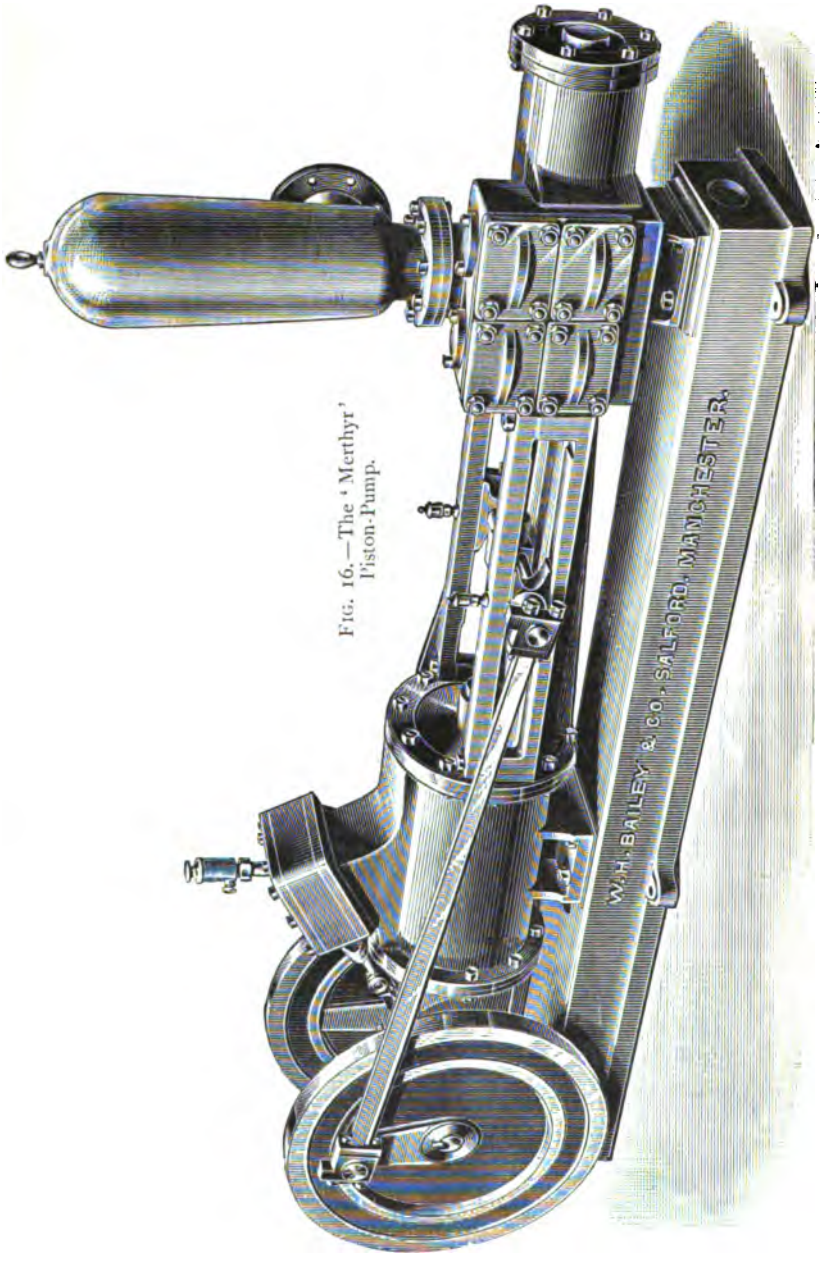


FIG. 16.—The 'Merthyr' Piston-Pump.

reader may compare the prices given below with those in the article on non-rotary pumps for similar size engines.

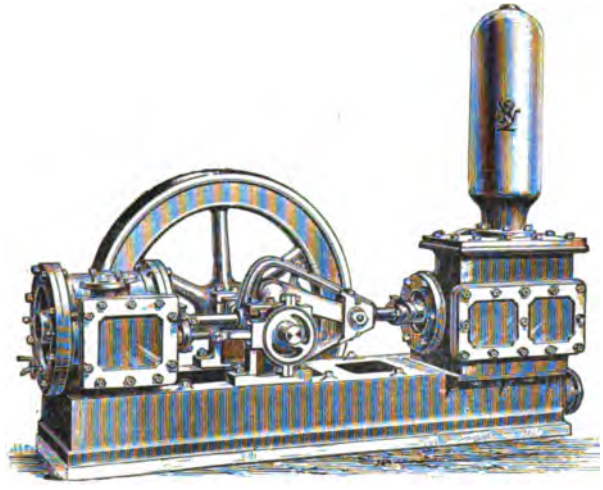


FIG. 17.—The 'Reliable' Bucket-Pump.

If the pumps be fitted with a condenser and a blow-through valve, the price will be increased by about 20 per cent.

In the following tables of prices we have given the number of the illus-

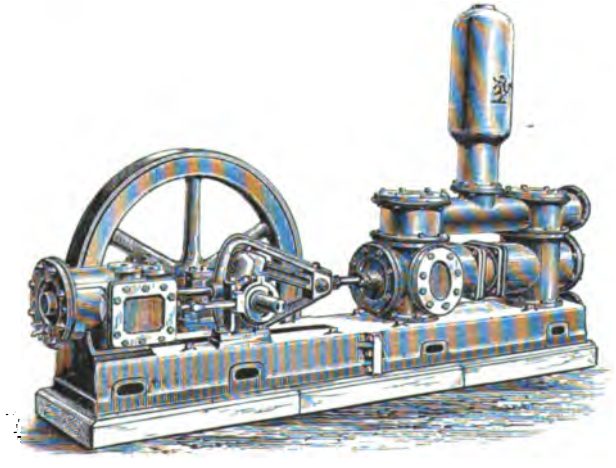


FIG. 18.—The 'Reliable' Ram-Pump.

tration of the pump to which each refers. For the cost of larger engines application must be made to the makers.

No. 1. Fig. 15.

Dia. of steam-cylinder in inches	Dia. of pump-cylinder in inches	Length of stroke in inches	Approx. delivery at given speed		Approx. Height of Lift in feet with 40 lbs. steam	Price	Extra for brass-lined cylinder
			Revs. per min.	Gallons per hour			
						£	£ s.
8	6	10	60	7,200	100	50	5 10
8	8	10	60	12,600	55	65	8 0
10	4	12	50	3,200	280	55	4 5
10	5	12	50	5,000	240	60	5 0
10	6	12	50	7,200	160	65	6 5
10	8	12	50	12,600	90	75	9 0
10	10	12	50	20,000	55	110	12 0

No. 2. Fig. 16.

Dia. of steam-cylinder in inches	Dia. of pump-cylinder in inches	Length of stroke in inches	Approx. delivery at given speed		Price	Extra for brass-lined cylinder
			Revs. per min.	Gallons per hour		
					£	£ s
12	6	1	40	7,200	120	6 10
14	6	15	40	7,200	150	6 10
14	7	15	40	9,950	160	8 0
16	7	15	40	9,950	190	8 0
16	8	15	40	12,600	200	9 10
18	9	18	33	16,200	250	13 0
18	10	18	33	20,000	275	15 0

No. 3. Fig. 17.

Dia. of steam-cylinder	Dia. of pump-cylinder	Length of stroke	Gallons per hour	Height lifted with 40 lbs. steam pressure	Price without governor	Including Pickering governor
in.	in.	in.		feet	£	£ s.
12	6	12	7,340	240	105	111 10
12	7	12	9,990	180	110	116 10
14	8	12	13,050	180	130	139 10
14	9	12	16,520	144	138	147 10
16	8	12	13,050	240	140	152
16	9	12	16,520	180	148	160

No. 4. Fig. 19.

Dia. of steam-cyl.	Dia. of ram	Length of stroke	Gallons per hour	Price
in.	in.	in.		£
6	3	6	1,800	47
7	3½	7	2,560	52
8	4	8	3,580	64
10	5	10	6,360	86
12	6	12	9,660	120

No. 5. Fig. 20.

Dia. of steam-cyl.	Dia. of ram	Length of stroke	Gallons per hour	Price
in.	in.	in.		£
14	7	14	9,800	150
16	8	16	12,800	200
18	9	18	16,200	240
20	10	20	20,000	300
24	12	24	28,800	380

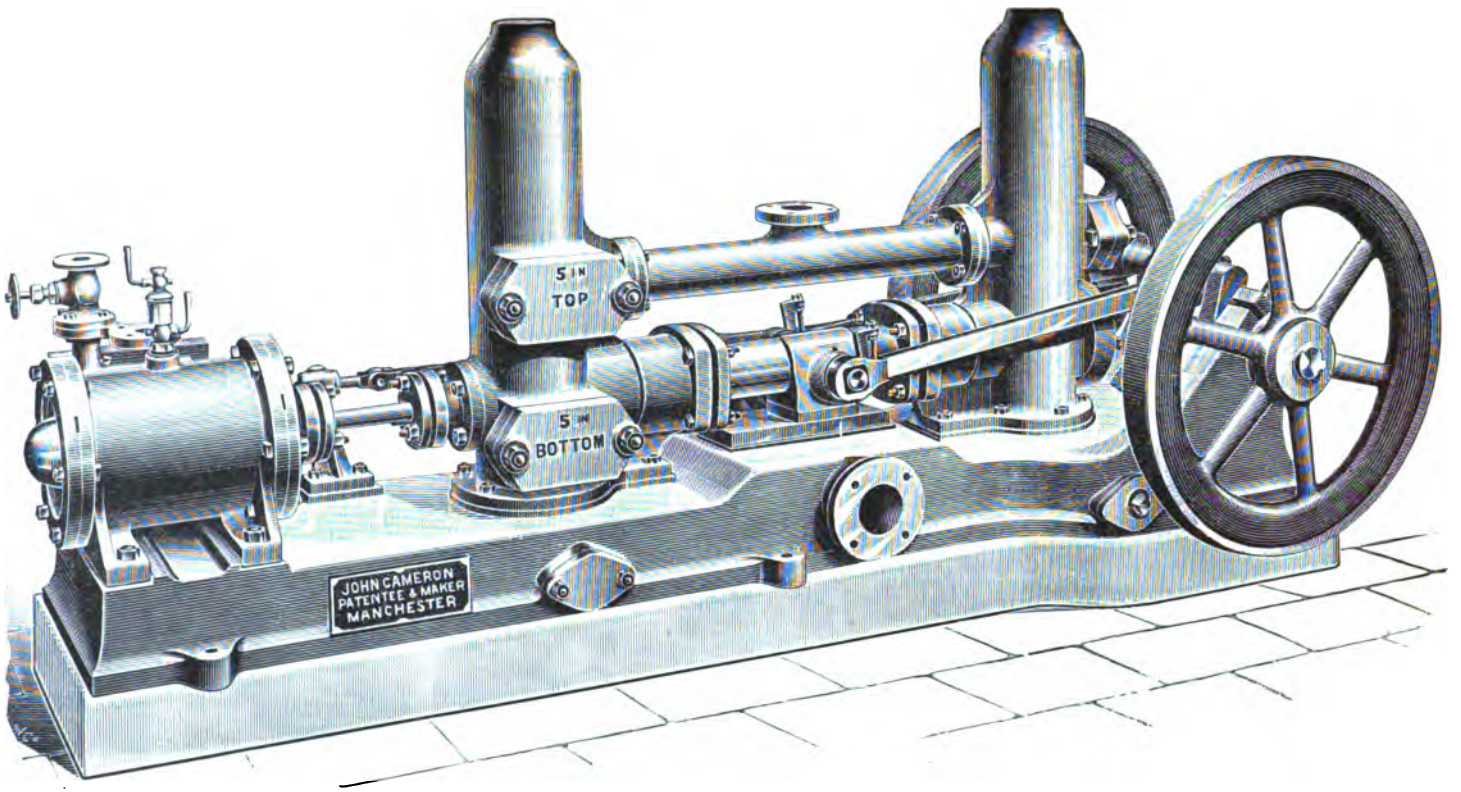


FIG. 19.—Cameron's Ram-Pump.

Duty.

Pumps of this type attain a higher range of duty than those of the non-rotary type; makers claim that they are from 30 to 50 per cent. more economical. The use of the fly-wheel enables power to be stored up at one part of the stroke and given out at another, thus permitting the steam to be used expansively, cutting off at about three-fourths of the stroke. In the absence of data which, for reasons that will be found at a later page, it is difficult to obtain, we are unable to give the duty of these pumps.

1. SINGLE STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES WORKING DOUBLE-ACTING PISTON-PUMP.

In Fig. 14, which represents Turner's piston-pump, the engine has a piston working in the pump-cylinder with a rod passing through the latter. To that part of the rod which passes beyond the outside pump-cover is fixed a crosshead, to which are attached a pair of connecting-rods, connecting the fly-wheels to the pump. It will be observed that the fly-wheels are mounted between the engine and the pump.

Figs. 15 and 16 are illustrations of Messrs. W. H. Bailey & Co.'s 'Cymric' and 'Merthyr' piston-pumps respectively. In the 'Cymric' pump the engine and pump stand on separate pedestals, and are united by a long distance-piece. The steam valve-chest is fixed alongside the steam-cylinder. This pump is made in sizes from 3-inch steam-cylinder and 1½-inch pump-cylinder, and 6-inch stroke to 10-inch steam and pump-cylinders, and 12-inch stroke, and is designed for steam pressures up to 100 lbs. and lifts up to 300 feet. It has only one fly-wheel.

The 'Merthyr' pump has two fly-wheels mounted behind the steam-cylinder, and attached by connecting-rods to a crosshead working on slipper-guides, and placed between the steam and water-cylinders, and fixed to the steam and pump piston-rods. The steam-valve chest is located on the top of the steam-cylinder, and is cast with it. The valve, as in the other pumps of this class, is a slide, and is operated diagonally by an eccentric on the crank-shaft. This pump is suitable for heights up to 300 feet.

Fig. 17 represents Messrs. Jos. Evans & Sons' 'Reliable' bucket-pump. The fly-wheel and crank-shaft are in the same relative positions as in fig. 14, but the arrangement will be seen to secure greater compactness. It has one connecting-rod working within a bow crosshead. In this design the water-cylinder is fitted with a leather-packed piston instead of the usual steel spring-rings. To prevent misconception it may be necessary to explain, particularly to those familiar with the Cornish system of pumping, that the term 'bucket' is applied in many parts of the country to a leather-packed piston, and has nothing in common with the Cornish bucket, which is a reciprocating valve.

2. SINGLE STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES WORKING DOUBLE-ACTING RAM-PUMP.

Fig. 19 is Mr. John Cameron's double-acting ram-pump. The steam-cylinder and fly-wheels are mounted on opposite ends of the bed-plate, the pump barrels and air-vessels occupying the intervening space. The piston-rod and the pump-rod are in one piece, the force being thus communicated in a straight line. The connecting-rods are coupled one on each side of the ram to a collar on the slipper-guide, which also acts as a balance and support for the ram, and prevents any undue wear. As will be seen, the valve box doors shown in one pump chamber on the side have for an obvious reason to be located in the end of the other pump chamber. Access to the bottom of each suction chamber is obtained by the hand-holes shown

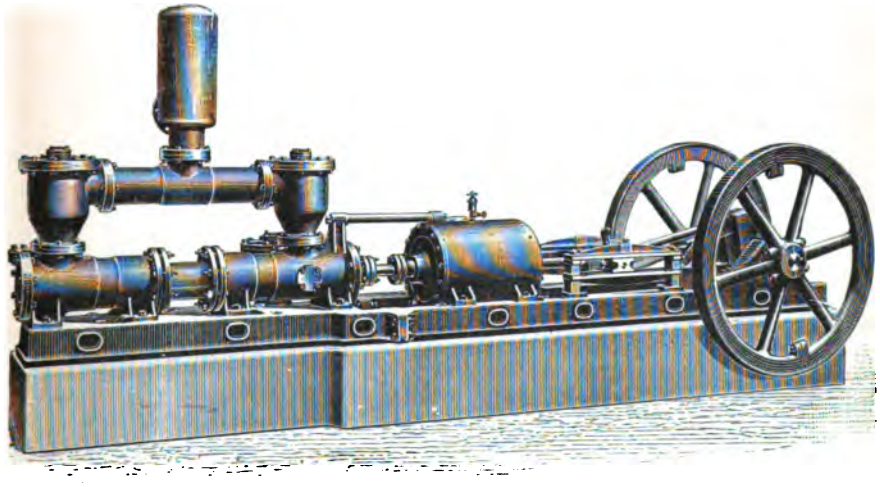


FIG. 20.—Pearn's Ram-Pump.

closed in the illustration, one on each side of the suction opening. The pump-barrels and chambers and air-vessels are one casting. The rams are outside packed.

In Messrs. Frank Pearn & Co.'s double-acting ram-pump, fig. 20, the steam-cylinder occupies the centre of the bed-plate, having the fly-wheels and connecting-rods behind it and the ram chambers in front. The pump-barrels and valve-boxes are made separate. There is only one air-vessel. Whilst the details are differently arranged from those of the previous engine the principle of action is precisely the same. When fitted with a condenser and blow-through valve, the exhaust steam is turned into the suction and condensed, provided the proportion of the steam-cylinders to the rams is not too large. It can be made extra strong for forcing up to 1,200 feet vertical.

In another arrangement of ram-pumps the steam-cylinder has been placed between two single-acting rams, behind one of which the fly-wheels have been mounted.

In fig. 18 we have the ram arrangement of the 'Reliable' pump, where the bucket is replaced by a double-acting ram or plunger working into two working barrels, an arrangement known as the 'Centre Outside-packed Plunger.' The attachment to the piston-rod is a direct centre connection, the rod being bolted to the front end of the plunger.

3. TWO STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES WORKING TWO DOUBLE-ACTING RAM-PUMPS.

A duplex arrangement of Messrs. Pearn's double-acting ram-pump is shown in fig. 21. It is specially designed for heavy lifts in mines. The bed-plate is made in sections to allow of its being got down the shaft.

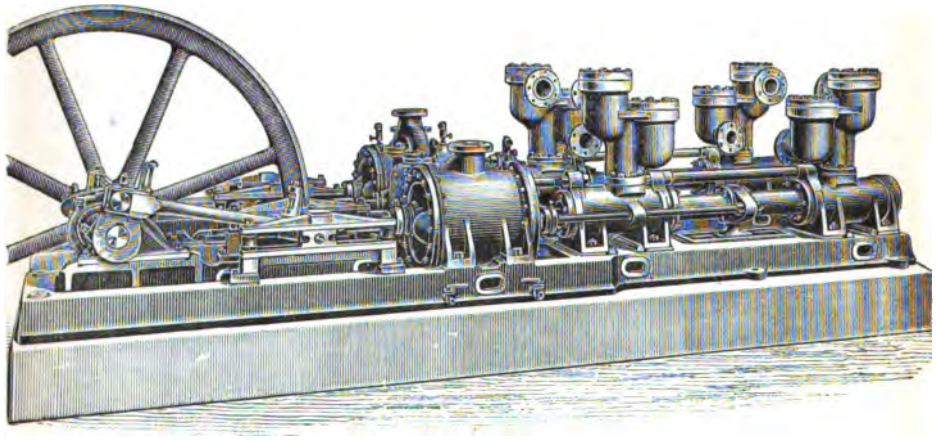


FIG. 21.—Pearn's Duplex Ram-Pump.

4. THREE STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES WORKING THREE DOUBLE-ACTING RAM-PUMPS.

The principle of duplication has been carried a stage further by the union of three steam-cylinders. In one design each engine is distinct within itself, but yet combined in its action with the others. The arrangement is an expensive one, but the fact that an accident to either of the engines or pumps does not interfere with the action of the others is of some importance. There are three pairs of single-acting ram-pumps (or three double-acting pumps). Each pair of pumps has its own steam-cylinder. A single fly-wheel serves for the whole, and is mounted at one

end of the machine, in a line with the central pumps. The three piston-rods are connected to the same crosshead, consequently the stroke of each set of pumps is simultaneous.

Messrs. R. Warner & Co. are the makers of a triple ram-pump, in which, by the use of a tooth-wheel geared in a pinion on the fly-wheel shaft, the speed of the pump is reduced below that of the engine, a corresponding increase of power in the pump being the result.

B.—COMPOUND STEAM-PUMPS.

The compound principle of steam-cylinders is one which is rarely resorted to in engines of the rotary class. A reason for this is not far to seek. By using a heavy fly-wheel a fair amount of expansion can be obtained with a

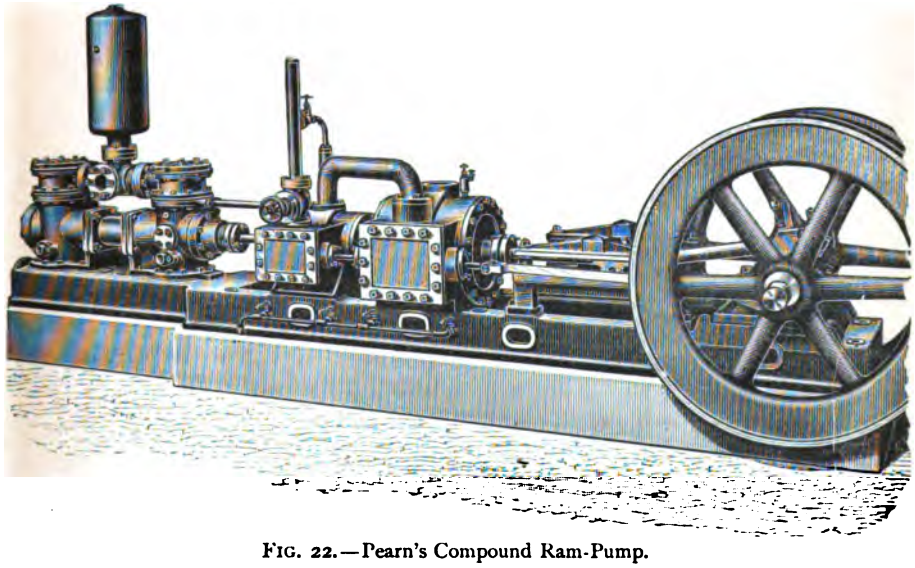


FIG. 22.—Pearn's Compound Ram-Pump.

single cylinder (by means of a cut-off steam valve, working on the back of the slide-valve or otherwise, and actuated by a separate eccentric on the crank-shaft). If it suit the miner's purpose better to employ a rotary than a non-rotary engine, it will give, for small and medium size engines, sufficient expansion to prevent an extravagant consumption of fuel, and the extra expansion to be obtained by employing a second cylinder would not compensate for the increased size of the engine, the additional cost, and the extra space required, and besides, as a portable engine, it becomes a much less useful machine. With the non-rotary engines the case is quite different. These will give only a very low ratio of expansion under the most favourable circumstances, and then an initial pressure of steam largely in excess of the load and a great piston speed must be adopted. The com-

pound principle in this case is an absolute necessity for large engines if the least regard be paid to economy. Very few makers appear to advertise compound rotary engines, which of itself is a good indication of the opinion of practical men on this point.

COMPOUND STEAM-CYLINDER, EXPANSIVE, CONDENSING ENGINES, WORKING DOUBLE-ACTING RAM-PUMP.

The engine depicted in fig. 22 is Messrs. Pearn's Compound ram-pump. It is claimed to be suitable for use as an underground pumping-engine and to be economical in the use of steam, cutting off at about three-fourths of the stroke and expanding the rest. It is made either to work high pressure or compound and condensing, and is so designed that it may be easily transported down the shaft and through drifts and levels. The cylinders and pumps are fitted on one bed-plate, thus making the whole self-contained.

C.—RIEDLER STEAM-PUMPS.

The pump proper, as here described, can be made in any style that may be deemed advisable. It may be built in the form of two or three single-acting plunger-pumps, or as double-acting plunger-pumps, or even as a piston-pump; or it may be found advantageous to use the differential principle, building each pump with two different size plungers, one about half the area of the other.

In almost all cases the best arrangement for mines will be to use horizontal engines, either compound condensing, or triple-expansion condensing, and to place one pump directly behind each steam-cylinder. In every case it must be a rotary engine, as the principle is not applicable to non-rotary engines. The type to be used will depend upon the quantity of water required, the total lift, and the space obtainable. The engines themselves may be either Corliss, slide-valve, or poppet-valve; but for underground work they should, of course, be made either as simple as possible, or to combine simplicity with economy, and preferably should be ordinary single-cylinder engines or compound Corliss engines.

The peculiarity of the Riedler pump lies in its mechanically controlled valve, which is closed by means of a spindle projecting into the valve chamber, and moved through a lever or rod by the same eccentric which operates the steam-valve a few seconds before the valve should close entirely; and when the speed of the water is considerably reduced, so that a partial closing will offer no appreciable obstruction, the lever or rod referred to moves toward and closes the valve; the arm then recedes and removes all pressure from the valve, leaving it free for the next stroke. Ordinary pump valves are left to operate by themselves, and are liable to irregularity, and necessitate a very small lift, thus throttling the water passage and requiring extensive circumferential passage.

The Riedler valve gear insures absolute regularity in the action of the

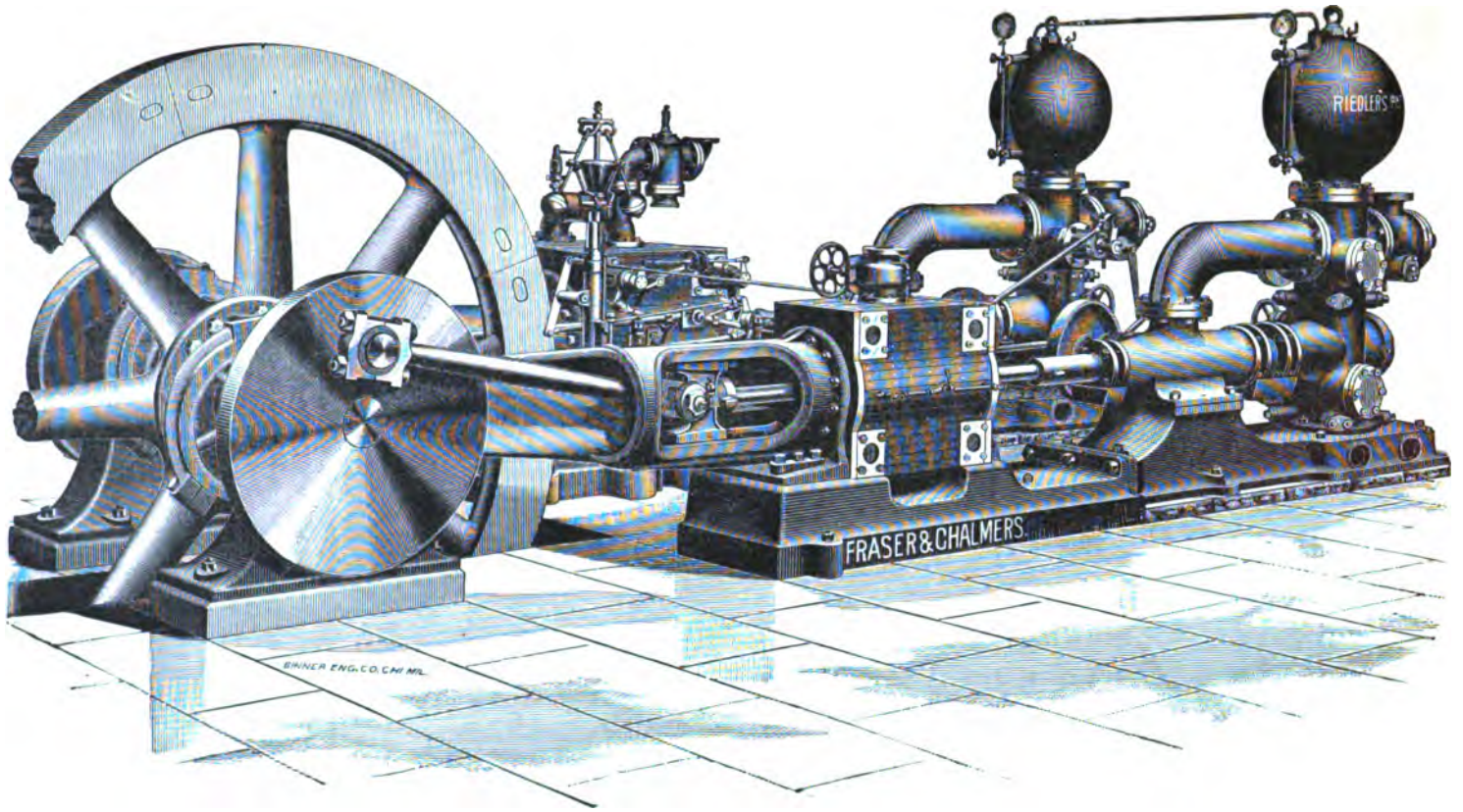


FIG. 23.—The Riedler Differential Pump.

pump-valves, allows full stroke, and diminishes the wear of the surface of the valves. Riedler valves require smaller size seats to be kept tight; also a smaller valve chamber, thus allowing great safety in the construction, and are well adapted for any kind of high-pressure pumps, and for large size pumps. The mechanism is exceedingly simple and easy of adjustment. It has been constructed in various ways; the pump-valves may be worked by cams or eccentrics; in some the closing levers are used to remove the pressure of a spring from the back of the valve before its time of opening; in others the lever is furnished with a spring, and in yet other constructions a small hydraulic plunger is used instead of a spring.

The valve and valve-seat are circular in form, and made of high grade bronze. The valve has a lift of from 1 to 2 inches, and an area of such amount as to reduce the speed of the water through the same to less than 4 feet per second. In other words, the valve area is figured entirely on the basis of plunger displacement.

The valves are so arranged that they can open freely and automatically to full lift at the commencement of the stroke, and remain open practically the entire stroke, thus avoiding throttling; but at or near the end of the stroke the valves are controlled by positive motion, thus preventing slip and enabling the pump to be run at a very high speed, in fact, at any desired speed. They are easily accessible. In case of obstruction between valve and valve-seat a very simple device prevents injury to the mechanism. From a record of over 825 pumps, the average life of these valves has been found to be about five years. In high-speed pumps, and also in pumps used for impure water, springs are inserted either between the valve and its gear, or in the rods of the gear, thus allowing a compression of the spring without injuring the valves, the seats, or the gear in case any hard material gets between the sides of the valve. These springs serve to accommodate the action of the valve to any variable pressure or speed, and are so arranged that the average resistance of the valves cannot compress them.

For a detailed description of the valve gear the reader is referred to the historical notes and figs. 12 and 13.

The first experience was made with this system as far back as 1884, when several engines for deep mines were built. They met at once with great favour; in one coal mine in Bohemia, in the course of four years, eight underground mining pumps on the Riedler system have been built. Since 1888 a large number of such pumping engines have been built in Austria, Germany, Belgium, France, Spain, and Italy, and are stated to have worked with great success in a number of deep mines in Bohemia, Silesia, Westphalia, and Belgium. About the year 1893 they were introduced into the United States by Messrs. Fraser & Chalmers, of Chicago and London, and appear to have rapidly grown in favour with mining engineers. They are already in use in several deep mines, raising water in some instances 1,800 feet high and upwards in one lift, at high speed. These pumps are also at work in Mexican and African mines.

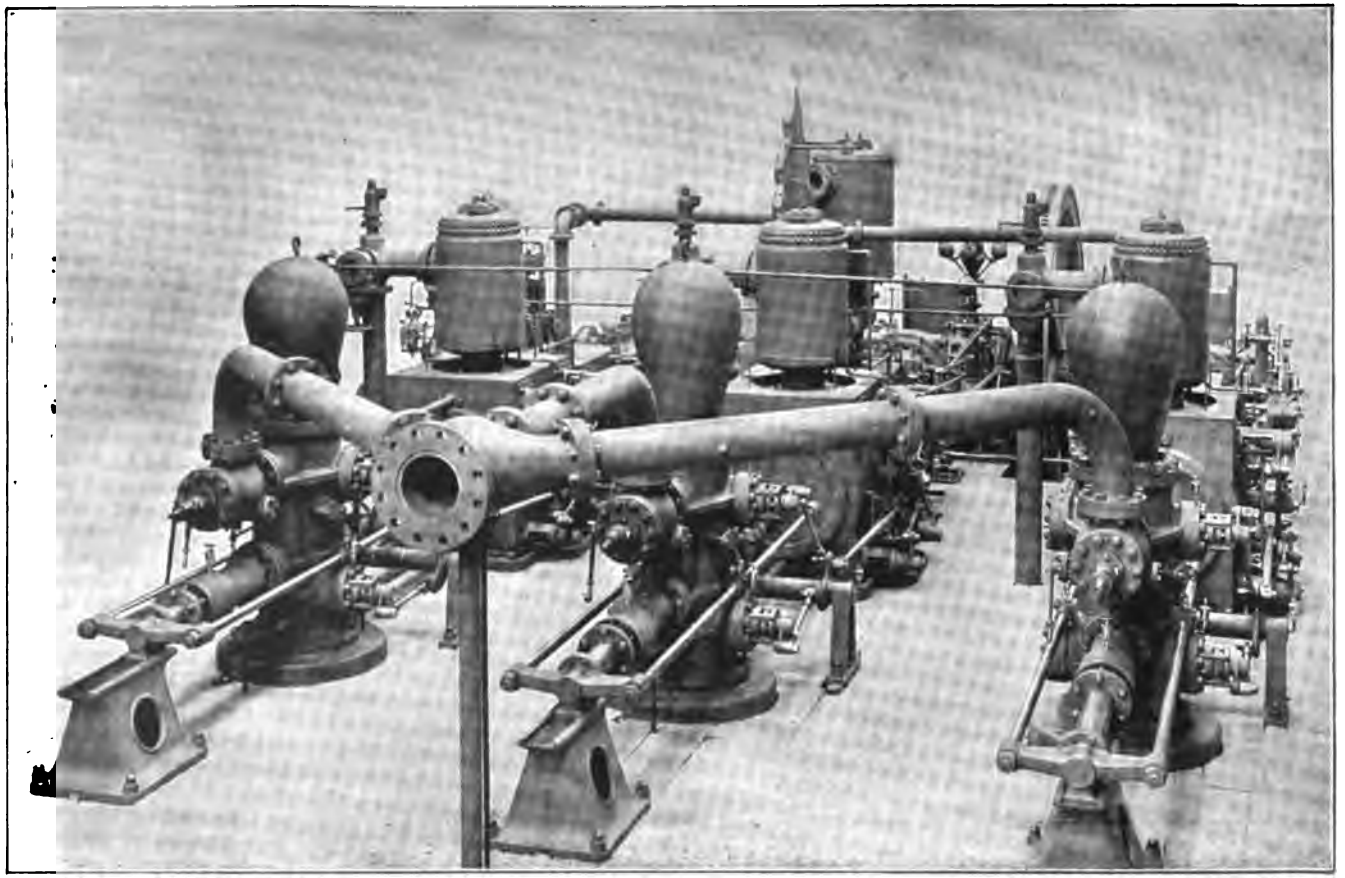


FIG. 24.—The Riedler Differential Pump.

THE RIEDLER DIFFERENTIAL PUMP.

The following description of the Riedler Differential Pump, of which figs. 23, 24, 25, 26 are examples, has been supplied by the makers.

A differential pump is practically a double-acting pump with but two valves. By arrangement as shown in the illustration, an equal amount of work is done on each side of the steam-piston during one revolution. In a single double-acting pump four valves are required, one suction and one discharge valve for each end of the double-acting plunger. A single differential pump, however, requires but one suction and one discharge valve for but one of the plungers, the main plunger. The differential pump has the advantage of always being primed, as will be seen by referring to fig. 26, where the column pipe 'D,' the discharge space 'C,' and the differential plunger chamber are always in connection. Thus the total pressure due to water head is always on the differential plunger 'H.' In other words, as long as there is water in the column pipe the pumping engine will always have a resistance to overcome even should suction be lost. The arrangement, therefore, prevents unduly severe hydraulic strains on the different pressure parts.

Having only half the number of valves, this form of pump is simpler than the double-acting pump, and is used until the capacity becomes so great that the valves would be too cumbersome. When this capacity is reached it becomes necessary either to make a duplex or triplex differential, or to use a double-acting pump instead. The double-acting pump valve would be half the size of the differential pump valve for the same total capacity. When pumping against high pressures, the air-chamber is made of seamless structural steel, or flange steel, so as to prevent leakage of air. Reference to the illustration (fig. 26) will show that the water enters the suction pipe 'A,' passing into the suction air-chamber and thence into the suction funnel 'B.' It should here be noted that the large casting (which acts as a substantial base for the pump) and the suction funnel 'B' form in the upper part of this casting a large suction air-chamber insuring efficient action of the suction valve 'E.' When the main plunger 'J' moves toward the right, it draws in its displacement of water through suction valve 'E'; on its return stroke to the left, the suction valve having been mechanically closed, it forces a volume of water equal to its displacement through the discharge valve 'F,' half of this water passing out into the column pipe 'D,' the other half passing down and following the differential plunger 'H.' The discharge valve 'F' now being closed, the main and differential plungers which are connected by means of side rods move again to the right, the main plunger again drawing the water through the suction valve 'E,' and the differential plunger displacing its volume and forcing the same through the discharge pipe 'C' into the column pipe 'D.'

The cross sectional areas of the main and differential plungers 'J' and

'H' are generally made in the proportion of about 2 to 1, so as to equalise the work done on both forward and return strokes, in other words, equalising

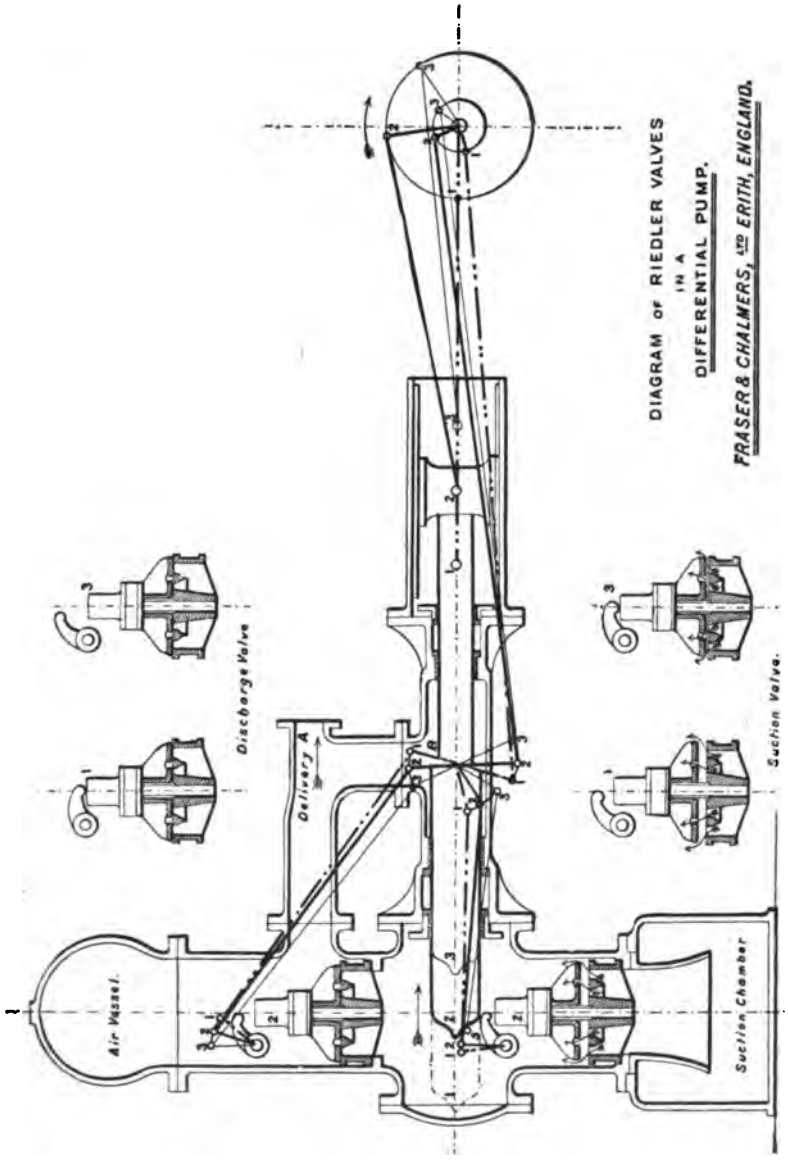


FIG. 25.—The Riedler Differential Pump.

the work as is the case in a double-acting pump. The rods 'G' are the side rods connecting the crossheads of main and differential plungers. It will be noted that these side rods are always in tension.

In large pumps a cast-iron guide is generally furnished on which the differential plunger crosshead, which is provided with a shoe, works. This is to prevent wear of the stuffing-box of the plunger. The main plunger being connected to the piston-rod of the engine does not require a guide.

It will be noted that in front of the discharge 'C' and connecting to the column pipe 'D' is a clack valve, which in illustration is shown closed. This valve is for the purpose of preventing the water in the column pipe from being run off when it is desired to take out the valves or examine interior parts of the pump. When the pump is working this valve is invariably kept open, but can be closed when it is desired to stop the pump, by means of the levers on outside of clack-valve chamber. These valves are especially necessary in pumps where either side may be run alone due to injury to one side or the other. It is a preferable form also, because should an ordinary stop valve be used instead, more time would be consumed in closing the same, and by carelessness it might not be opened when starting up, and damage therefore be done to the pump. The clack valve, of course, will open automatically as soon as the pressure inside of the pump exceeds the pressure in the column pipe.

All types of our pumps are fitted with proper drains and by-passes from column pipe and from discharge chambers to suction chambers, also with shifting valves and necessary arrangements for lubrication.

The following is a description supplied by the makers of the Riedler Pump built at Chicago for the Boston and Montana Consolidated Mining Co., and shown in fig. 23.[1]

The engine is a Twin Compound Condensing Corliss Engine, with 16-inch diameter initial cylinder, 25-inch diameter expansion cylinder, 24-inch stroke of piston. The cylinder heads and sides are steam-jacketed. The pump has two differential plungers of the same stroke (24-inch), the large end being 8-inch diameter, and the small end $5\frac{5}{8}$-inch diameter, made of bronze.

This pumping machinery has ample capacity to pump 900 gallons per minute from 600 feet level, the present depth of the mine. At the same time the pumps will be built in such a manner that they may be later on removed to the 1,200 feet level. All the change required in case of such removal would be that the plungers will have to be taken out and others of one-half the capacity substituted. Considering the small size of the plungers, such a change would be inexpensive. The pumps are built strong enough to withstand the pressure due to 1,200 feet head of water.

The pumps are of the differential type, arranged so that on the forward stroke water is drawn in from the suction tank by the large plunger, while at the same time the small plunger forces out into the delivery pipe a volume of water equal to its displacement. On the backward stroke the

[1] This pump was installed at the Leonard Shaft. (See Report by Capt. Thomas Couch, p. 55.)

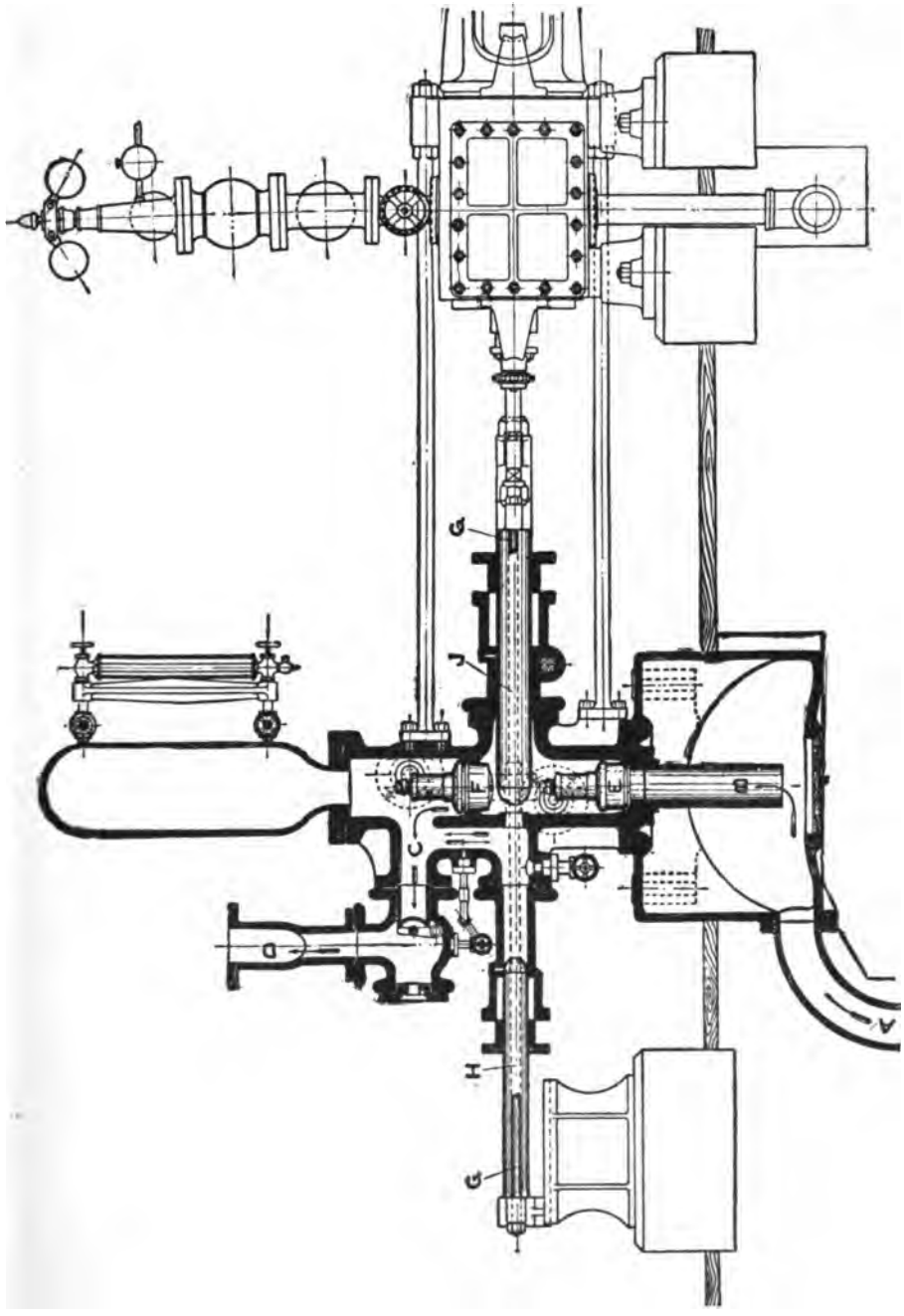


FIG. 26.—The Riedler Differential Pump: longitudinal section.

large plunger forces the water drawn in at the previous stroke. Of this water, one-half fills the space vacated by the small plunger. In this manner the delivery of the pump is constant for each stroke. The pumps are constructed under the Riedler patents. Two such complete pumps being included in the plant, the delivery is nearly constant. We furnish a speed governor with the pumping engine. All the parts of these pumping engines are made of such size that they can easily be lowered through the shaft and handled in the mine.

For condenser and air-pump we use those of the independent type. The steam for working them will be taken from the low-pressure steam-jacket, and through this arrangement we accomplish two things:—

First.—The steam-jacket is always well drained, as the steam circulates through it all the time, and

Second.—The condensed steam from the jacket has a chance to re-evaporate in the cylinder of the air-pump. So it will easily be seen that the power required to operate the air-pump is, in this matter, obtained without expense, considering that the drainage water from the jackets would otherwise run to waste, as it would not be practicable to pump it up to the surface.

The whole pump end is made of high-class bronze metal, so that it may effectually withstand the chemical action of the mine water. All valves and seats are made on the interchangeable system, so that at any time we shall be able to supply new valves without delay.

The pump end of the air-pump, as well as the condenser, is also made of bronze, and all the injection and overflow piping is of copper with brass fittings. The condenser is of the jet type.

The steam-cylinders are fully jacketed, not only on the cylindrical part, but also on each end. The high-pressure cylinder is jacketed with steam at boiler pressure. The low-pressure jacket is supplied with steam of somewhat lower pressure. This steam is taken from the high-pressure jacket, pressure being reduced by passing through a reducing pressure valve. The exhaust piping to the condenser is arranged in such a way that either the high-pressure or the low-pressure cylinder may exhaust direct into the condenser. This permits the use of half of the engine, should the other by any reason be disabled or need overhauling. In case the low-pressure side of the engine is used alone, steam is applied to it through another pressure-reducing valve.

A steam-receiver is placed near the high-pressure cylinder. This receiver is so constructed that it also serves as a separator of water that may have been condensed during its passage through the steam-pipe. In order to minimise the loss through condensation the pipe is to be covered well with non-conducting material.

This pumping engine is intended to work with steam pressure of 115 lbs. at the engine. In order to insure against possible losses in pressure, due to the excessive length of steam-pipe, the boilers are built to work under a

continuous pressure of 130 lbs., but it is not believed that the drop in pressure will be as high as 15 lbs. We allow for such an excess of pressure simply in order to have an ample margin, taking into account the deterioration of the boilers in the course of time.

Reference has been made to the Riedler pump supplied to the Boston and Montana Consolidated Copper and Silver Mining Co. The following report, by Captain Thomas Couch, the superintendent, under date Butte City, Montana, January 12, 1894, is of interest and value :—

'At the Leonard shaft the Riedler pump was put in operation about six months ago. The engine of this pump is 16 and 25 × 24. Pump plungers are 8 and $5\frac{5}{8}$ × 24. These are made of bronze. Before this pump was put in place, all the hoisting from the East Colusa shaft was transferred to the Leonard, so that all the fuel used at the East Colusa after this change was for steaming the old pumps then in use in the old shaft. This gave us an opportunity to get at the exact fuel cost of running them. The Riedler pump having boilers for its exclusive use enables us also to tell the exact cost of running it, and the difference in fuel so far has been nearly 60 per cent. in favour of the Riedler. This pump works admirably. Its capacity rating is at 90 revs., and it does our work with about 33 revs., so we are safe in the event of a large increase of water, which is not likely for some time. This pump is double in its construction. One side can be operated independently of the other if it becomes necessary to do so, and either side working singly has sufficient capacity to keep the mines free from all incoming water. So far we are well pleased with this equipment. In the event of serious accident, we have a duplicate set of pumps made up from those previously used, all in place, so our position in that regard is safe. The Riedler pump has a copper column, and I think all the pumps should be similarly furnished. The water in both the Mountain View and Pennsylvania Mines is very bad on iron.' [1]

At the Anaconda Copper Mine, Butte, Montana, a specially designed Riedler Differential Pump was laid down. As is well known, the water is so extremely acid that no combination of metals has yet been found that will long withstand its attack. In view of this the valves were arranged so as to be removed from one side whilst the pump is running, by coming up on specially designed connections. The pump end is made entirely of a high-grade special bronze. The steam end consists of a cross-compound condensing Corliss engine. Provision is made for the running of either side alone at maximum speed, if desired, or if injury necessitating such action occur to one side or the other. Capacity 750 gallons per minute against a head of 800 feet when running 90 revolutions per minute.

For the Amarillas Mining Co., Mexico, a Duplex Single-acting Riedler Pump was supplied, driven by a horizontal cross-compound condensing slide-valve engine. Capacity 250 gallons per minute against a head of

[1] This pump is set in the 600-feet station.—S. M.

1,250 feet. The Creston Colorado Co., Mexico, was furnished with a similar engine and for the same service and head.

Messrs. Fraser and Chalmers installed a Riedler plant in the Drum Lummon Mine, belonging to the Montana Mining Co., in 1895. Mr. R. T. Bayliss, general manager, in his report to the directors, October 23, 1895, made the following statement relative thereto :—

'*Riedler Pumping Engine.*—This plant, which has recently been erected in the 1,600 ft. level, was rendered necessary owing to the greater quantity of water met with in the developments at the bottom of the mine, and consists of a Duplex Differential Riedler Pump, with plungers 3¼ in. and 5¼ in. in diameter, and 24-in. stroke, actuated by a Horizontal Compound Condensing Corliss Engine, with cylinders 16 in. and 25 in. in diameter, and 24-in. stroke, and has a capacity of 400 gallons per minute against a head of 1,230 feet, when running at 90 revolutions. At the present time it is working to about one-third of its capacity; therefore, it will be able to handle, without difficulty, any quantity of water which we may reasonably expect to encounter in these workings. The erection of this pump has resulted in a saving of not less than 60 per cent. in the consumption of fuel hitherto necessary for operating the ordinary steam pumps which were previously situated in the 700, 1,000, and 1,200 ft. levels, and it is evident that by this economy of fuel alone, the Riedler pump will repay the cost of its erection in eighteen months. In addition to the saving in the consumption of fuel, a considerable economy is effected in the labour and repairs necessitated by the operation of the pumps formerly in use; and it may be safely assumed that the introduction of the Riedler pump will enable us to unwater the mine at an expenditure not in excess of 25 per cent. of that incurred under the old system. I may mention it is only within the past two years that the Riedler pump has been introduced into the United States, although it has been for some time extensively used in Germany, Austria, and other European countries.'

The engineers of the mine, Messrs. R. W. Raymond and T. A. Rickard, reported thus :—

'The admirable Riedler pumping plant recently placed on the 1,600 ft. level will permit operations to be prosecuted to any extent, on or above that level, without fear of any disturbance of the regular work of the mine by a sudden influx of water. This pump is undoubtedly adequate to handle all the water that can be encountered above the 1,600. It is now taxed to only one-third of its capacity; and most of the water comes from above the 1,600 level.'

The following remarks are extracted from a letter issued by the makers, Messrs. Fraser and Chalmers, dated Chicago, August 19, 1897.

'We beg to direct your attention to the splendid duty performance of the Riedler Pump built by us for the Chapin Mining Co., Iron Mountain, Michigan. The Riedler pump at the Chapin Mine is a Triplex Differential Riedler Pump, plungers 6¾ in. and 9⅝ in. diam. × 30-in. stroke, driven

by a Horizontal Triplex Tandem Compound Condensing Corliss Engine, steam-cylinders 22 and 36 in. diam. × 30-in. stroke; capacity 2,200 U.S. gallons per minute against a total head of 1,700 ft. when running about 74 revs. per minute. It is designed to run economically with steam pressure at engine of 110 lbs. per sq. in., or by compressed air with a pressure of 60 lbs. per sq. in. at engine. For this reason the engine is equipped with our latest improved form of full stroke Corliss valve gear. This pumping engine is undoubtedly the largest underground pumping engine in the world.

'At the present time the pump is working on the 1,310 ft. level, and raising 2,200 gallons of water per minute, but later it will be lowered to the 1,700 ft. level. We do not expect, therefore, the fullest economy from the pump at its present level, but we have nevertheless reduced the fuel consumption at the Chapin Mine from 30 tons to 8 tons in 24 hours; that is, the pumps previously used for the duty consumed 30 tons of fuel per day, while the Riedler pump requires only 8 tons per day.

'It will be to the advantage of any engineer or mining company considering the purchase of a pump, to visit Iron Mountain and see the Riedler pump at work. So well satisfied is the Chapin Mining Co. with the Riedler that they have given us an order for two more pumps, duplicates of the three referred to.'

The pump mentioned (see fig. 24) is provided with two jet condensers, the air-pumps being driven by direct connection with crank shaft of main engine. The arrangement is such that any one or two, or the three pumps may be run as desired, with either one or both condensers. There is ample reserve capacity. Mr. Jas. Mac Naughton, the general manager of the mine, expects that ordinarily only two pumps will be required; this will leave one pump in reserve and provide against 'drowning out.' The steam pipe, which is 7 inches in diameter, is covered with 3-inch thick carbonate of magnesia. The column pipe is 13 inches outside diameter, the lower sections being $\frac{5}{8}$ inch thick. As the Chapin Mining Co. have a very large compressor, the pump will eventually be driven by compressed air.

B.—NON-ROTARY HORIZONTAL ENGINES

A.—SIMPLE STEAM-PUMPS

Whether regarded from the extent of their use, the diversity of their application, or their general utility and ready adaptability to the purposes of underground pumping, the machines of this class are the most important of all direct-acting pumping engines. A classification based upon the character of the water end would give us, broadly, the following groups, namely,

I. Piston-pumps.
II. Plunger-pumps.

Still confining ourselves to the hydraulic part of the machine, we find that each of these groups may be subdivided thus :—

I. Piston-pumps : *a.* spring-ring packed.
b. leather packed.
II. Plunger pumps : *a.* internally packed.
b. externally packed.

As will presently be seen, extension of the basis for classification to the steam end of the pump would necessitate a more subtle and elaborate grouping of types, as the multitude of these pumps in use in all parts of the world differ chiefly in the appliances for admitting, distributing, and controlling the steam. In many instances the divergence is of a comparatively trivial nature, merely sufficient to avoid infringement of any existing patent rights; in other cases the difference is more marked, involving, in fact, quite distinct principles of action in the valve mechanism.

As there would be no particular advantage in carrying classification to such a limit, the pumps will be considered as far as practicable in the order indicated.

It must be understood in the following descriptive outlines of pumps of the respective classes named that we are only giving the more general characteristics, referring the reader to subsequent pages for details of specified pumps and their distinctive features.

Description.

The pump has two cylinders, usually on the same bed-plate—a steam and a water-cylinder, which are in a straight line and are connected by a distance-piece, the end flanges of which form the covers for both cylinders. The piston-rod attached to the steam-piston passes through both covers, and is also attached to the pump-piston, thus giving the two pistons an identical movement.

The steam-cylinder is surmounted by a cylindrical steam-chest containing a starting piston-valve, or piston-valves, for shifting the main slide-valve. This piston-valve is actuated either direct by steam from the main cylinder through shooting-ports at or near the ends of the latter, or by tappets (levers) moved by the main piston, with or without the interposition of an auxiliary valve, or by reversing valves in the main cylinder ends, moved by the piston, which admit steam from the main cylinder to either end of the starting-valve.

In some engines the steam-chest is placed on the side of the main cylinder; Evans's 'Cornish' Pump and the 'Tipton' Pump are examples of this type.

We have observed in dealing with pumps of the rotary class that the steam-valves are of the ordinary slide-valve type, and are actuated by eccentrics on the crank-shaft. In the class of pumps now under consideration, there being no rotary motion by which, through the intervention of

an eccentric or crank, the main steam-valve may be actuated to give steam alternately to each end of the steam-cylinder, the steam-piston is made, with suitable mechanism, to help itself. The usual method is to utilise the reciprocating motion of the main piston-rod to operate a lever or a tappet attached to or in communication with an auxiliary or starting-valve, shifting it over, and setting the main valve in motion, and securing the necessary juxtaposition of the steam-ports for admitting steam to the main cylinder, and thus propelling the main piston to the other end of the cylinder, where it again sets the starting-valve in motion.

The main valve is usually of the D type, and is generally shifted by the starting-valve mechanically. In a few instances it forms a part of the starting-valve, partaking, thereby, of its motion.

In some leading pumps, notably the Worthington, Knowles, and Cameron, the B-type valve is used.

In a few cases the main valve is moved by the action of steam admitted to it by the movement of the starting-valve. The main valve may thus be moved *mechanically* by the starting-valve or by the *direct impact of steam.*

In some pumps there is an auxiliary valve underneath the main valve (in addition to the starting-valve) operated by a tappet or tappets struck by the main piston at the end of its stroke, by which steam is admitted to the starting-valve which gives motion to the main valve.

Sufficient has been said of the steam valve-gear to indicate the nature of the mechanism most generally employed. We shall presently consider this subject at some length.

The pumping part of the machine comprises a large chamber, the bottom portion of which consists of a cylinder. The upper portion of the chamber contains two delivery-valves, one at each end, and surmounting the chamber, and midway between the valves, is an air-vessel into which the delivery-valves discharge. The upper part of the chamber is a separate casting, and is removable for examination of the valves, etc. A pair of suction-valves in the bottom part of the chamber admit the water to each end of the pump-cylinder alternately, which, it must be added, does not extend the whole length of the chamber, in order that the piston may communicate with each set of valves.

Mode of Operation: Piston-Pumps.

The *modus operandi* is as follows:—A stroke of the piston to, let us say, the right-hand end of the cylinder will force the water which fills the space between the suction-valve, the piston, and the delivery-valve, through the latter into the air-vessel, the pressure of the fluid keeping the suction-valve closed. Meanwhile, the opposite end of the chamber having been emptied more or less by the previous stroke, the suction-valve immediately admits water into the space between it, the retreating piston, and the delivery-valve. At the completion of the stroke of the piston to the right, the right-hand end of the chamber is emptied of a great or the greater

portion of the water it contained, and the left-hand end of the chamber and the cylinder as far as the piston are full. The return stroke of the piston forces a large portion of this body of water through the delivery-valve at that end (the left-hand) of the chamber towards which the piston is moving, the right-hand end of the chamber simultaneously filling. The displacement of water by each stroke of the piston is, of course, a volume the length of the stroke and the diameter of the cylinder, and these being known, the quantity of water pumped at each stroke can be easily calculated, slip being allowed for. From what has been said it will be gathered that these pumps are double-acting, that is, they force water at each stroke. The sections given further on will enable the reader more clearly to comprehend this fact, and will explain better than can be done by words the nature of not only the water part of the class of pumps under consideration, but also give him a better general idea of the steam part, and the pump as a whole, although, as we have already pointed out, each pump has its own particular arrangement of the steam valve gear and other parts. The principle which secures the double action is the same in nearly all these pumps.

The piston may be packed with leather or spring-rings; the pressure and the circumstances under which the pump is used determine the form of piston most suitable.

Pumps having leather-packed pistons are sometimes termed by their makers 'bucket-pumps,' although they have little in common with the bucket-pump used in Cornish pump-lifts, except the packing. They are, in fact, a solid piston leather-packed, whereas the Cornish bucket is a leather-packed (or 'leather geared') valve.

Plunger-Pumps.

Generally the plunger-pump differs very materially in the arrangement of its parts in the water end from the piston-pump. Like the latter it is double-acting, the principle of action being similar. There are several types of plunger-pumps. In one form the water end consists of a chamber of similar appearance to that used for piston-pumps, the plunger working double-acting in a cylindrical case or barrel extending the greater part of the chamber and open at each end to the upper and lower parts of the chamber, where the delivery and suction-valves are respectively located. In this type the plunger is internally packed, and as in the case of the piston-pumps the packing can only be examined or repaired by removing the upper portion of the chamber. In the Worthington 'Plunger and Ring Pattern' the plunger works through a deep metallic ring bored to accurately fit the plunger. The latter is located some inches above the suction-valves, thus providing a settling chamber into which any foreign substance may fall below the wearing surfaces.

In another form of internally packed pumps the plunger is an open cylinder divided at the centre by a plate in the casting into two distinct

chambers, or, in other words, two hollow plungers. As these always remain full of water, they have practically the same effect as closed plungers. The piston-rod passes through and is bolted to a boss in the casting. Plungers of the foregoing types are only used where the water is clean and the working head does not exceed 150 to 200 pounds to the square inch.

In one form of the type known as the 'Outside-Packed Plunger-Pump,' there are two separate and distinct pump-chambers, each containing, in the upper part, a delivery-valve, and in the lower part, a suction-valve.

These chambers are united by a pair of stuffing-boxes, through which the plunger, termed a 'double-ended plunger,' works, and delivers water from each end. The attachment to the piston-rod is what we may call a 'direct centre connection,' the rod being bolted to the front end of the plunger, which, it will be seen, is double-acting. To distinguish this type from the one next noticed it is sometimes referred to as the 'Centre Outside-Packed Plunger-Pump.'

In another form of the 'Outside-Packed Plunger-Pump' there are two single-acting plungers which work into each end of a cylinder having a central partition, and deliver from their inside ends.

There is a direct central connection with the piston-rod for the front plunger and a crosshead and side rods making a side connection for the rear plunger. The outer end of each plunger works through a stuffing-box at the end of the water-chamber.

Externally packed pumps have this great advantage over those packed internally, that the plungers can be quickly packed, and can always be kept in order without the necessity of disturbing joints or even of stopping the engine. The plungers not passing through any sleeve or stuffing-box in the centre of the cylinder, but being 'outside-connected,' it is not possible for any water to leak by, or to pass from one end of the cylinder to the other, and the displacement of water at each stroke is exactly equal.

Piston and Plunger-Pumps compared.

We will now consider briefly the respective suitable and appropriate spheres of action of piston and plunger-pumps. Firstly, with regard to piston-pumps; these are suitable for only moderate lifts, say up to about 500 feet, and for pumping fairly clean water, free from grit, and not too strongly impregnated with sulphurous or other acids.

It is a lighter, smaller, and more compact machine than the plunger-pump, and, consequently, is more easily handled and transported from one point to another. Its use is, therefore, more or less obligatory in shafts, dips, and galleries, where the space is very limited, and the nature of the rock and the situation make excavation costly and difficult. In such circumstances, and particularly if the water be either gritty or acidulous, the pump-cylinder should be provided, as already stated, with a removable lining, and gun-metal should be largely employed in the construction of the water-end of the pump.

It appears to be the practice in many American mines to use piston-pumps in preference to plunger-pumps because of their low cost and the advantages enumerated. The pump is run until it gives out, when a duplicate pump is taken down and the other sent to the surface for repairs.

The parts most subject to wear are the piston-packing and the cylinder, and the wear of these parts, even when constructed of the very best material, when pumping corrosive water, carrying more or less grit, is generally rapid and serious, and the pump may be losing water to a considerable extent for some time before it is discovered. The time taken to disconnect and return the pump to surface for the necessary repairs, involving, perhaps, reboring of the cylinder and refitting, would, in many instances, have serious effects. The wisdom, therefore, of having a duplicate pump in reserve is obvious, as is also the great advantage of having the pumps fitted with composition linings.

The advantages of a plunger-pump compared with a piston-pump for heavy mine work, especially where the water is bad, and grit or sand is more or less present, are so manifest and manifold, that where the exigencies of the case admit of their use, no enlightened engineer would begrudge their extra cost. They are suitable for the greatest pressures, dealing successfully with lifts of 1,000 feet or more. They are, for heavy mining work, made enormously strong, and having practically no wearing parts in the entire cylinder end but the stuffing-box packing, they are not only very efficient, but conspicuously durable, compared with piston-pumps. The stuffing-boxes being in sight, are always open to inspection, and leakage can be easily detected and immediately stopped whilst the pump is running, by setting up the packing.

In favourable contrast with piston-pumps the wear is thrown upon soft packing, which adapts it especially to pumping gritty water. In one type of plunger-pump known as the 'Outside-Packed Plunger-Pump' the piston-rod does not enter the pump-cylinder, and is therefore not exposed to the action of corrosive water. Another advantage of this type, as we have already pointed out, is the perfectly equal displacement of water at each stroke.

Where acidulous water has to be handled, the plungers are made of brass or gun-metal, as are also the valve-seats, and other metallic parts of the valves.

Steam-Valve Gear.

In the preliminary remarks on the steam-valves, it was observed that the feature in which the various pumps of this class differ from one another more than in any other is the mechanism for introducing the motive power. In giving as full and complete an account of the different valve gears adopted and the principle of their action as our space will permit, a little repetition of remarks made a few pages back must be forgiven.

The following must be read in association with the chapter dealing with the history of the steam-pump, where the origin and development of the Worthington pump is considered.

The remarks which follow are only intended as a short summary of the kinds of valve gear in use in certain pumps; the reader is referred to the articles on the several pumps of this class for a more minute description, with the aid of sections, of their respective valve gears, and the *modus operandi* thereof.

Without going into too subtle distinctions the valve arrangements may be divided into the following classes, according to the method employed for throwing the main valve :—

I. Mechanically by a starting-valve set in motion by internal tappets by the main piston.

II. Mechanically by a starting-valve set in motion by external tappets or levers by the main piston or piston-rod.

III. Mechanically by an auxiliary valve, set in motion by external tappets or levers, by the main piston or piston-rod, thus giving steam to a starting-valve.

IV. By the direct impact of steam through the intermediary of an auxiliary valve or otherwise.

The great *desideratum* in the valve gear of an engine of this class is to provide against the engine becoming either 'centred,' or overrunning its stroke and breaking the cylinder-cover.

We have seen that in Worthington's pump as developed in the years 1840–1844 the steam-valve was partially reversed by tappets and levers connecting with the main piston-rod, the throw being completed by a spring and arrow-headed bolt. In later pumps the main valve was operated by an auxiliary piston. Succeeding these was the Worthington and Baker pump, with relief-valve motion. To this pump, it is believed, the B or double cavity steam slide-valve was first applied. It was employed with the ordinary arrangement of cylinder-ports on an elevated face, but steam entered under the end of the valve, at the end of the cylinder opposite that supplied by an ordinary single-cavity valve, when moved in the same direction. An arm on the piston-rod operated tappets on the valve stem.

As has been already remarked (p. 59) the main steam-valve is generally of the D type, but in some of the classes the B type is used. In a few instances, the 'Excelsior' and 'Caledonia' pumps to wit, the main valve forms a part of the starting-valve, partaking, thereby, of its motion.

In the two last-named, the main and starting-valves consisted of a cylindrical spindle, two pistons near the centre forming the main valve, and a double-headed piston at each end forming the two starting-valves.

The valve gear of Colebrook's pump was of a unique character; it had no starting-valve, and was, as far as we know, the only pump placed on the market without small valves or tappets, and that had only one valve,

which was of the piston type, and in equilibrium, and actuated by the exhaust steam.

In another pump, the 'Standard,' a circular piece or plug in the slide-valve directed the live steam coming from the main cylinder to either end of a cylindrical slide-valve.

The auxiliary valves may be external to the cylinder as in the 'Imperial' pump. They are operated by steam transmitted to them by the movement of the main piston, and the steam passes to either end of a plunger starting-valve, connected to which is an ordinary flat valve which gives full steam to the main piston.

The five last-named pumps do not now appear to be in use, but reference is made to their valve gear to show how busy inventive genius has been in the creation of ingenious, if eccentric and impracticable, devices.

In some pumps there is an auxiliary valve underneath the main valve, in addition to the starting-valve, operated by a tappet struck by the main piston at the end of its stroke, by which steam is admitted to the starting-valve which gives motion to the main valve.

In one type (the long-piston short-stroke 'Universal') the separate valve-chest is dispensed with. The main piston, which is longer than the stroke, is hollow, and contains a cylindrical valve-chamber, in which a long piston, constituting the slide-valve, reciprocates. The main piston is open at the top and sides between the ends, which are steam-tight to the cylinder, and the latter performs the functions of a valve in opening and closing the ports and steam passages.

One variety of pump, now apparently defunct, had no starting-valve; there was only one valve which was of the piston type, and in equilibrium, being actuated by the exhaust steam.

The 'Special' pump valve gear, which has been much improved of late years by Messrs. Tangyes, consists of a slide-valve of the D pattern, placed on the top of the steam-cylinder, and moved to and fro by a separate small auxiliary piston which is steam-moved.

In the Knowles pump an auxiliary piston working in the steam-chest, located on the main cylinder, is set in motion by the main piston mechanically, and carrying with it the main valve, which is a plain slide-valve of the B form, working on a flat seat, gives steam to the main steam-piston that operates the pump. To the main piston-rod is attached a tappet arm which gives motion at the end of each stroke, through the medium of a 'rocker bar,' to the valve-rod and thus to the chest-piston, which carrying with it the main valve, as stated, gives steam to the main piston.

In the A. S. Cameron pump the reversal of the auxiliary piston or plunger is accomplished by the use of two small valves, one in each cylinder end; the auxiliary plunger throws the main valve (B slide) mechanically, and thus instantly reverses the main piston. There is no external mechanism.

In the Blake pump the main cylinder is surmounted by a small second-

ary cylinder containing an auxiliary piston for actuating the main D slide-valve, which fits between two collars, by which it is mechanically moved. The main valve works on the top of a three-ported auxiliary slide-valve contained in a chamber in the bottom of the auxiliary cylinder. Into each end of the auxiliary steam-cylinder is fixed an immovable horizontal arm, to which is anchored a vertical lever. Fixed to the auxiliary valve are two long spills or rods, the outer ends of which take hold of the aforesaid levers, from which the valve obtains its motion. The motion which the levers receive is imparted by tappets in the main cylinder ends, which are moved by the piston.

The 'Davey Differential Valve Gear' was designed to secure such a distribution of steam as should cause no shock or slip in the pumps; and in the event of a sudden loss of load the safety of the engine; in short, to make the engine self-governing under extreme variations of resistance. This is effected by admitting steam to the engine in proportion to the resistance to be overcome, and in case of a sudden total loss of load reversing the steam to catch the piston. The distribution of steam is effected by coupling the motion of the engine with that of a piston having a uniform velocity. The engine is made to cut off steam by its motion, whilst the uniformly moving subsidiary piston is employed in admitting it. As long as the resistance to the engine is sufficient to prevent its motion becoming relatively equal to that of the subsidiary piston, steam is admitted up to the fixed point of cut-off; but should a loss of resistance, or a superior pressure of steam, cause the engine to acquire a speed relatively greater than that of the subsidiary piston, then the motion of the steam-valve would be reversed earlier, and the supply of steam would be adjusted to the altered conditions.

Construction; General.

The first direct-acting steam-pump ever constructed was used as a boiler feeder on board a canal steamboat, and ever since, both on board ships, in factories, mines, and wherever else steam power is used, it has found a useful sphere of operation in this direction.

Piston-pumps of the smaller sizes of this class have been very extensively used, and are very well adapted for the purpose named. The work is easy and the conditions are generally most favourable.

In underground mining operations the conditions are very different, and are generally very trying both to the action and the life of the pump. It is not an easy task to design a steam-pump that will meet the very exacting and variable requirements of mine work. The service is usually rough, severe, and continuous, and manufacturers always regard it as the severest test to which their engines can be subjected, and accordingly bestow special pains upon their design and manufacture.

The trials that await and beset the steam-pump when it passes down into the abysmal depths of the mine or colliery are multitudinous in number

and destructive in character. Plunged into the dark and reeking inferno a thousand feet or more from the light of day, the little engine has generally to perform its grim devoirs amid the most uncongenial surroundings and under the most unfavourable conditions.

When not immured in a station (the least unfavourable position for it), the pump is located either down a dip, in a gallery, alongside a winze, or in some other remote spot, exposed to falls of rock, fragments of coal, dirt and dust and wet, or it may, swung in the pump shaft, be the recipient of harder treatment still. Then the care and attention it gets from unskilful hands are often of the worst description, indeed, may be said to be conspicuous by their absence, and to the ills described must be added, in many instances, clumsy treatment or sheer neglect.

The worst foe to a pump's longevity is undoubtedly to be found in the character of the water that has sometimes to be handled—water which is highly mineralised, or which contains solid matter, such as grit, sand, or mud. In many instances, both these elements of destruction are present.

In many metalliferous mines the water contains either the sulphate of copper or the sulphate of iron, with occasionally free sulphuric acid. Professor Jones, as the result of analyses of water in the Stanley Mine at Idaho Springs, found that the most corrosive agent is ferric sulphate. This particular water did not contain free sulphuric acid. Whilst dilute sulphuric acid, as is well known, has no action on pure copper, this water had a very strong action on that metal, and on all the alloys which are commonly used for pipe columns. He had tried pipe columns of wood, iron, brass, lead-lined, and lastly of bronze. The last-mentioned material has withstood the action for over two years, while the ordinary wrought-iron pipe—especially when the steam was exhausted into the sump—only lasted about a week.[1]

At the Saratoga Mine, Gilpin County, where the water is also very corrosive, and Mr. Ernest Le Neve Foster attributes the action to free sulphuric acid, there was the same experience of the increased corrosive effects by exhausting into the sump. His experience was that a cast-iron pipe answered very well with cold water, and seemed to resist the action much better than wrought-iron.[2]

In the copper mines of Cornwall it has sometimes been necessary to line the pumps with thin slips of wood and to use brass plungers, and in some instances the water has been so highly acidulous that other parts of the pitwork had to be either brass-lined or entirely brass, such as working-barrels, valves, etc. In the Wicklow copper mines the water was so exceedingly corrosive that wooden plungers have been used. 'We have now at work *a wooden plunger-pole* made of this country beech. . . . The pumps are lined with wood which will save the inside from the action of

[1] Bulletin No. 6 of the Colorado Scientific Society; Paper by Professor Jones on 'The Action of Ferric Sulphate on Metals and in Corrosive Mine Waters,' June 5, 1897.
[2] *Op. cit.*

the water, and the flanges will be protected as much as possible by well-tarred hoods of canvas.'[1]

The evil of acidulous water is, in the case of steam-pumps, often aggravated, as shown in the examples given, by the increase of its temperature by exhausting the steam into it. Add to this the occasional presence of solids, such as grit or sand, and the reader can imagine the disastrous effects upon the internal hydraulic organism of the pump, its valves, piston, piston-packing, and, indeed, upon all the parts exposed to the action of the water.

Steam-pumps for the rough work mentioned should not have too great a number of external moving parts. Where wet, dirt, general bad usage, and neglect are the prevailing concomitants of its use underground it is not well to have too refined a machine.

The material of which the pump as a whole is constructed is a most important consideration; but in the matter of the water end it is doubly so. For heavy duty, and especially where the water is not only impregnated with acid, but carries grit, the pump should be constructed of the hardest iron it is possible to work, making the metal of considerable thickness, and the valve-seats should be made of gun-metal. Where the water is very corrosive, the valve-seats, valve-bolts, piston (or plunger), indeed, all the interior of the pump, should be made of brass, gun-metal, bronze, or phosphor-bronze. In some cases it is necessary for the water-cylinder to be cast entirely of gun-metal composition.

The water-valves should be easily accessible for inspection and repair, and removable either by ordinary doors or hand-holes, or by a quick and easy detachment of the upper section of the pump-chamber. To make these operations as expeditious as possible all bolts and nuts should be prevented from rusting together by occasionally loosening and rescrewing them. All water-passes and valves should be equal in area to the piston or plunger.

It is a good arrangement when the delivery-valves lie directly over the suction-valves, and the water in passing from one through the other is only slightly deflected around the plunger. Every change in the direction of the water currents involves loss of power, and wear and tear of the pump.

Separate valve-boxes are most advantageous, and are well worth the extra cost entailed. The 'Pot-Valve' form of mining pump is useful and very popular with mining engineers. The valves and seats can be readily taken out in one movement after the covers of the 'pots' are removed.

Every pipe should be run in as direct a line as may be practicable; there should be as few elbows and T's as possible. Where changes of direction have to be made, full round bends of pipe rather than regular elbows should be used, and Y's in preference to T's. It should be borne

[1] MSS. of the late Mr. Nicholas Kempston, quoted by the late W. Jory Henwood, F.R.S. ('Observations on Metalliferous Deposits and on Subterranean Temperature,' *Trans.* of the Royal Geological Society of Cornwall, vol. viii., part i., page 569).

in mind that elbows, etc., increase friction more rapidly than length of pipe.

Where the water is very gritty, and, owing to limited space and other circumstances, a piston-pump can only be used, the pump should be provided with a removable cylinder or pump-barrel (in other words a cylinder-lining), easily taken out when necessary and replaced by a new one.

The removable cylinder offers this other advantage; if it becomes necessary to locate the pump at a lower level in the mine, thus increasing the head to be pumped against, the original removable cylinder can be changed for one of greater thickness, and therefore smaller bore, and so enable the pump to be continued in use.

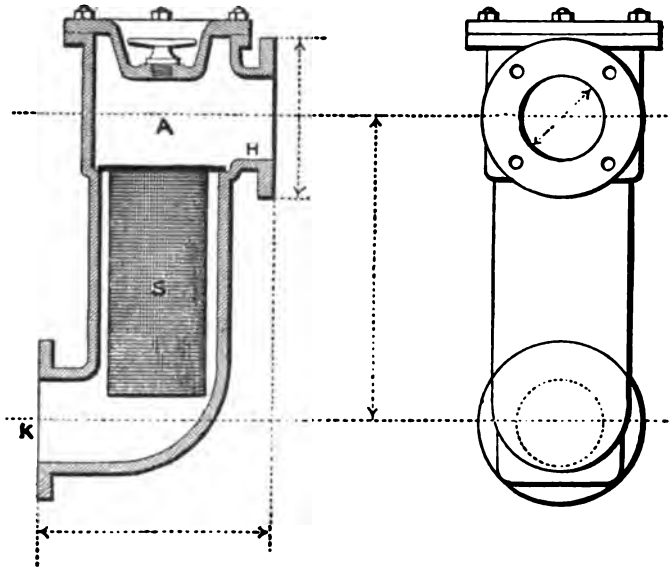


FIG. 27. FIG. 28.

Worthington Strainer Box and Strainer.

In some forms of pumps both the suction and discharge-valves are located above the pump-barrel or cylinder, so that the piston may be at all times submerged, and being thus always charged with water it works 'solidly.'

A 'retaining' or 'check'[1] valve should be attached to the delivery-pipe of all pumps where the column of water exceeds 50 feet high, or is of considerable length. It prevents much inconvenience and loss of time when examining the valves of the pump. It is also useful to have a

[1] The terms 'retaining' valve and 'check' valve mean the same thing; when placed at the bottom or foot of the pump range it is known as a 'foot' valve.

'retaining' valve connected to the suction range to keep the pipes and cylinder charged with water, so that the pump, when being started, is not obliged to free itself and the suction-pipe of air. This valve is always essential on a long suction-pipe, or where the suction lift is severe. In

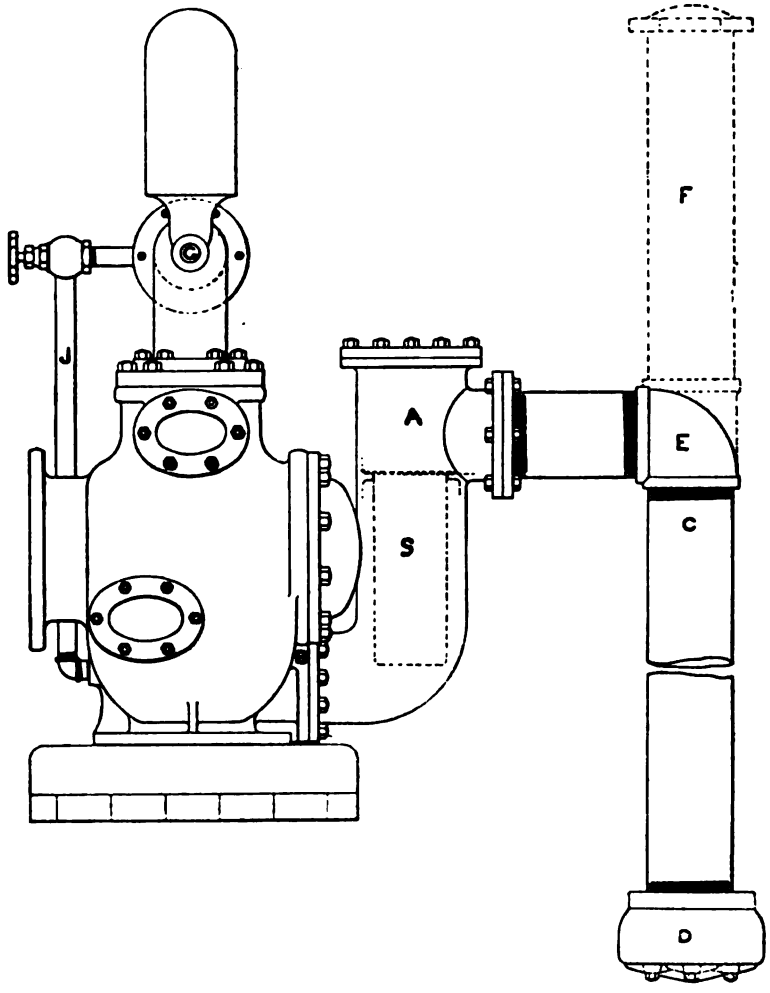


FIG. 29.—Worthington Pipe Connections.

such cases a vacuum-chamber, in other words an air-vessel, should be affixed at the head of the suction range, to provide an elastic cushion, against which the moving column may expend itself, rather than against the suction-valve, which the bucket or piston is striving to close. Indeed, an air-vessel on the suction, whether it be long or short, is always desirable ;

it is easily made by extending the suction-pipe upward, using a T connection (between the bottom flange of the pipe forming the vacuum-chamber,

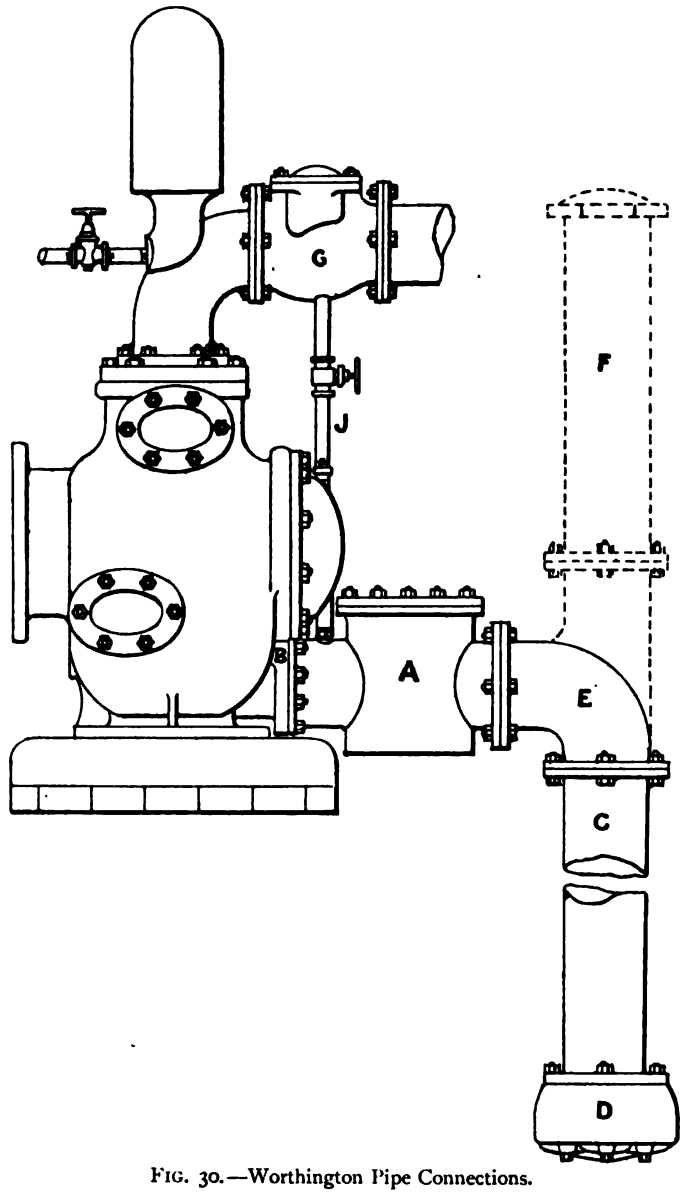


FIG. 30.—Worthington Pipe Connections.

and the top flange of the topmost pipe in the range) for attaching the suction to the pump. For running pumps at a high speed such a chamber

is absolutely indispensable. Its utility consists in causing a steady and uniform flow of the fluid through the suction-pipe, thus preventing pounding or 'water-hammering,' which is always incidental to long suctions when not thus equipped.

It is often necessary, and generally desirable, that there should be a strainer attached somewhere to the supply (or suction) pipe of a pump, on the same principle as the 'wind-bores' in Cornish lifts. The objection to placing it at the bottom of the pipe is the difficulty of reaching it in case it should be obstructed and require cleaning. A good plan is to have a basket-strainer inserted in the pipe, near the suction opening of the pump, with a hand-hole for withdrawing it for cleaning. Fig. 27 is a section showing a Worthington strainer-box and strainer; fig. 28 is an end view of the same. The flange K is attached directly to the suction opening of the pump, and the supply-pipe to the flange H. The basket-strainer, S, is of ample area, and can be easily withdrawn for cleaning through the hand-hole at the top. In the hand-hole plate a thumb-plug is provided which, if removed when the pump is stopped, admits air into the suction-pipe, and prevents the water from siphoning out of the water-cylinders, thus keeping the pump charged with water, and facilitating restarting.

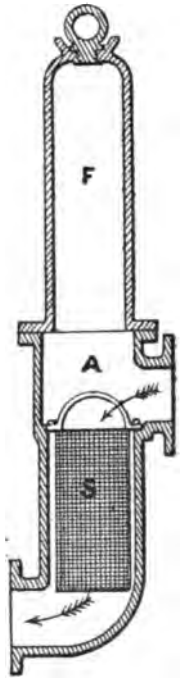


FIG. 31.—Blake Strainer Box and Strainer.

The annexed illustration, fig. 29, represents a side view of a Worthington pump in which the appliances mentioned are shown; D is the foot-valve on suction-pipe C; E an elbow connection to the strainer-box A; S, basket-strainer. It will be seen that the strainer-box and the elbow-pipe connection to the pump flange B are one casting. If a suction-chamber (F) be used, the elbow E is replaced by a T connection, as shown; J is a 'charging-pipe,' connecting the delivery-pipe *beyond* the check-valve with the suction-chamber of the pump. A check-valve should be placed upon the delivery-pipe to keep back the water when the pump is opened for examination or repair. In fig. 30, which gives a side view of the delivery-pipe, the check-valve is shown at G. It will be observed that in this case the strainer is of different construction from that previously noticed, and the connection to the pump is more direct.

In fig. 31 we have the arrangement of suction-chamber and 'strainer-basket' used with the 'Blake' pump. The arrows indicate the direction of the water; the upper arrow the inlet from the suction range, and the lower the point where it enters the pump-chamber. The priming plug is for use whenever it becomes necessary, as is sometimes the case with long suction-pipes, to charge the pump with water.

Reference has been made to the 'charging pipe; every well-equipped

pump is provided with this, the function of which is to connect the delivery-pipe *beyond* the check-valve with the suction-chamber of the pump, for the purpose of charging the cylinders and suction-pipe before starting, with water from the delivery-pipe, in case they have been purposely emptied, or the water has leaked out through the foot-valve. See J in figs. 29 and 30.

There should also be a 'waste delivery' or 'starting'-pipe, that can be led into any convenient place of overflow, in order that the pump at starting can free itself of air, while the pressure is kept from it by the check-valve. When the pump has properly started, the valve in the 'waste delivery' should be closed.

Air-Vessels.

An air-vessel is always attached to the delivery end of pumps, and in a long suction range one should also be fixed to the suction end. It should be fitted with a gauge-glass to show the quantity of air, and if it is working satisfactorily, and means should be provided for keeping it well charged with air; this is a most important point.

The function of the air-vessel is a most important one, and is generally so well understood that it will be sufficient if we state briefly that its purpose is to interpose an elastic agent between a propelling power and a resisting, inert, incompressible body. Its great value in all the classes of pumps treated of in this work is so well established that makers always include them in their specifications. If so useful in double-acting engines, the air-vessel is an absolute necessity in those that are single-acting, especially when running slowly, if a serious shock is to be avoided at the beginning of the stroke, when the plunger is suddenly impacted upon an incompressible body at rest. Its great value here is due to the elasticity of the air, which, by absorbing the excess of pressure at the beginning of the stroke, and giving it out when the original power is spent, converts the intermittent discharge of the water into a continuous one, thus economising power, as well as securing the other benefit named.

The volume of the air-vessel is governed by the 'head' of water, the kind of pump (whether single or double-acting), the size of the pump cylinder, the length of the stroke and the speed; in other words, by the displacement of water, the pressure under which it is effected, the action of the engine, and the speed at which it works. All sorts of proportions may be found in practice; they have been made as large as twenty times the size of the pump-cylinder in single-acting pumps. From eight to ten times would be a good proportion provided it be expressed vertically, for single-acting pumps, and say about half this ratio or somewhat less for double-acting pumps. Height is essential to effectiveness in an air-vessel, mere lateral extension of volume adding little to its value. In the case of underground pumps circumstances often impose a limit to the height of the air-vessel.

The necessity of a regular supply of air to the air-vessels of all pumping engines has led to the introduction of various systems of force-pumps and separate air-chambers, which have all been more or less failures, either from an inadequate supply of air or being too cumbersome in application. The accompanying design illustrates Wipperman and Lewis's apparatus for this

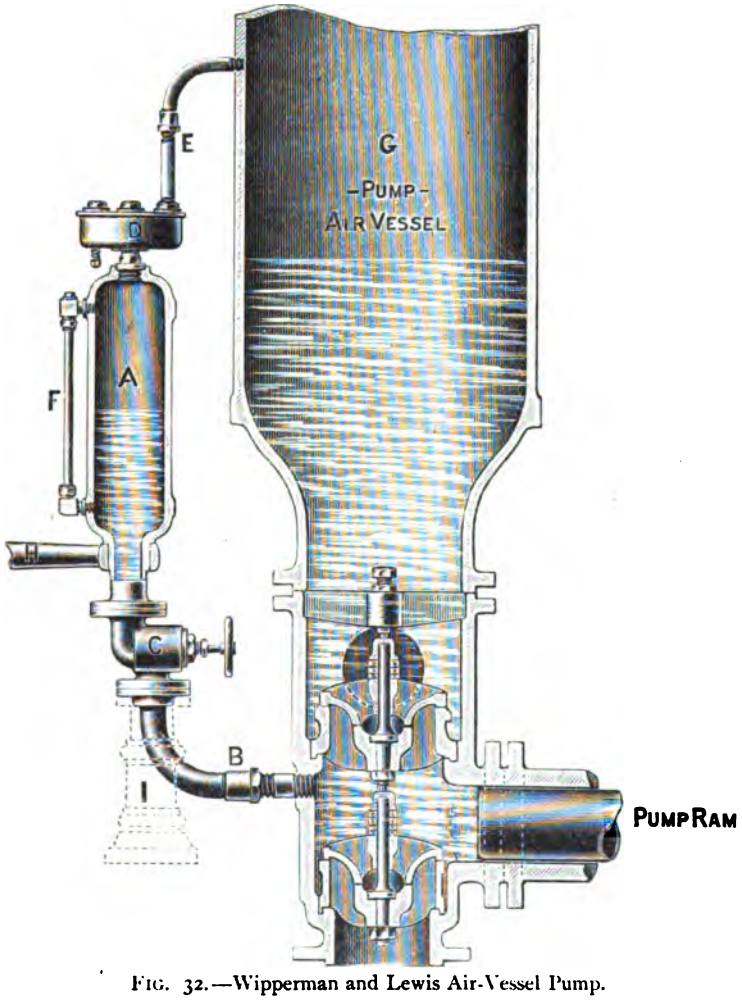


Fig. 32.—Wipperman and Lewis Air-Vessel Pump.

purpose, as applied to an ordinary pumping engine; it consists of a cylindrical vessel (A, fig. 32), which has no working parts, the water itself forming the piston; at the bottom of the chamber is a small pipe (B), fitted with a regulating cock (C), which is attached to the pump valve-box, immediately below the delivery-valve; at the top of the vessel is fixed a small

gun-metal valve-box, fitted with inlet and outlet air-valves, and from this a delivery-pipe communicates directly to the air-vessel.

The action of the apparatus is as follows, viz.: When the main pump draws its water it will partly empty the vessel A, the amount being indicated by the gauge F, and regulated to a nicety by the cock C; on the return stroke of the pump-plunger, the whole of the air drawn into the chamber A is sure to be delivered into the air-vessel G, because the pressure in the main pump, when delivering, is in all cases greater than on the suction side.

The advantages of this simple contrivance over others are many: The supply can be regulated as in no other apparatus; there can be no friction, as there are no working parts; it is perfectly noiseless in action, and may be attached to any engine, whatever the construction, at one-tenth the cost of an ordinary charging-pump.

Pipe Columns.

The material of which the pipe columns (known in Cornwall as 'pumps') are made must now claim our attention. The practice varies in different countries. In the mines and collieries of this country, where, owing to the proximity of the raw material and the foundries, carriage is not a serious factor, cast-iron is almost universally used. In the mines of the United States, Canada, Mexico, the Transvaal, and other countries, owing to the high first cost of castings, the difficulties and expense of overland[1] or ocean transportation, in some cases both, and generally the absence of suitable plant for handling heavy castings underground, pipe columns are almost invariably made of wrought-iron or steel.

Cast-Iron Pipes.—As cast-iron has a comparatively low tensile strength, and, practically, no elasticity, and is consequently liable to fracture under a severe and sudden stress, pipes made thereof must be of considerable thickness for great pressures and strains. Nevertheless, as we have already stated, it appears to be the almost universal practice in this country to use such pipes.

Whilst wrought-iron pipes are only about one-third the weight of cast-iron pipes of the same capacity, the cost of the raw material per ton is considerably—perhaps as much as one-third—greater. There would, therefore, appear to be very little difference in the cost of the raw material per pipe, but undoubtedly wrought-iron pipes require more skilled labour, and involve more trouble and cost in manufacture. The mining districts being generally well served with foundries, carriage is in the majority of cases not an important matter.

Cast-iron pipes are better adapted for the blows to which they are exposed, and general rough treatment underground, than those made of

[1] At the present time (Feb. 1898) the greater part of the supplies are brought in by pack animals from Hazelton, at the Forks of the Skeena, the rate to Manson Creek (Omineca district) amounting to seventeen cents per pound.'—*Annual Report of Minister of Mines British Columbia, for the year ending 31st December* 1897, p. 515.

wrought-iron, and possessing more firmness and rigidity, they make a more stable erection in the pump shaft. Other points in favour of the cast pipes are their greater resistance to the action of acids and their greater durability, wrought-iron pipes having little surplus thickness to resist the attacks of oxidation and corrosion.

In Cornwall the pipes are usually made of Scotch pig-iron and 'foundry scrap' (fragments of old cylinders, beams, pumps, etc.), which make a stronger grain and a tougher casting than if made entirely of pig-iron. Welsh pigs have occasionally been used, but these are dearer than the Scotch. Elsewhere the Scotch, Lancashire, or Welsh is used, depending on the situation of the works and the specification of the engineer.

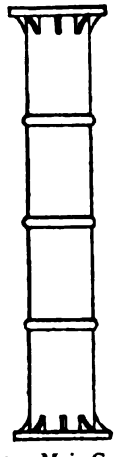


FIG. 33.—Main Column Pipe.

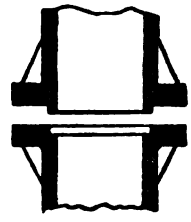


FIG. 34.

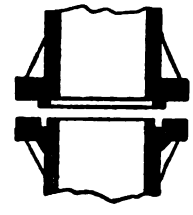


FIG. 35.

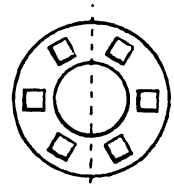


FIG. 36.

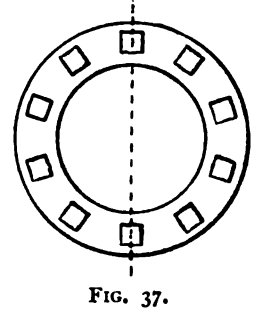


FIG. 37.

Pipe Joints and Flanges.

The usual length of cast-iron pipes is 9 feet for medium and large sizes, and from 6 to 7 feet for small sizes, the thickness varying according to the pressure of water.

The pipe is flanged at each end, the flanges being generally strengthened with brackets (as shown in fig. 33), which are cast with it. Additional strength is sometimes imparted by bands as shown. This is the invariable practice in the Cornish mines. The flanges are cast quite flat, and are not faced. In the collieries, where the lift is often much higher, the pipes are usually provided with spigot and faucet ends, such as figs. 34 and 35, or similar thereto, and the flat part of the flange is faced.

Figs. 36 and 37 are plans of flange and bolt holes for small and medium pipes, say up to 10 inches diameter, and above that size, respectively, the

dotted line indicating where the measurement must be taken. Figs. 38, 39, 40, and 41, are bends of various curves, fig. 42 a T piece, and figs. 43 and 44 are Y pieces.

In ordering of the founder such lines and measurements should be given as, in the case of bends, will give not only the degree of curvature, but the angle of the flanges, and, in branch pipes, the angle both of the flanges and the branch or branches. In all cases the diameter of the flanges should be given in addition to that of the pipes.

For a long lift it conduces to economy to graduate the thickness of the pipes according to the pressure, the heaviest being placed in the bottom. In a lift of, say, 600 feet, the pipes for the first 100 feet could be made very light, for the next 100 feet heavier and stronger, the third 100 feet still stronger, and so on to the bottom.

Care should be taken in fixing the pipes in position to thoroughly stay the column, in order to prevent straining of joints. In the suction range, although the column is short and the weight correspondingly small, it is quite as necessary to support the pipes, as a strain would be likely to open a joint and let in air.

In Cornish pitwork the appliances for supporting and staying the pump column are known as 'yokes.' These are semicircular bands of wrought-iron, with a straight projecting piece at each end, and holes for bolts, see figs. 45 and 46. They are used in pairs as shown, and are placed round the pump under a band or the flange, and the ends bolted together, and resting upon 'bearers' (balks of timber) fixed across the shaft, relieve the cistern of some of the enormous weight, and keep the column from vibrating. They are also used for suspending sinking lifts.

When the water is corrosive the pumps, as already stated, are lined with thin narrow slips of wood, as are also other parts of the pitwork.

Pipes should be treated with a composition of some suitable kind to retard adhesion of deposit and the attacks of corrosion; Dr. Angus Smith's is almost universally employed for this purpose.

DIAMETER AND THICKNESS OF FLANGES, AND THICKNESS AND WEIGHT OF PIPES SUITABLE FOR LIFTS NOT EXCEEDING 300 FEET.

Diameter of pipe	3	4	4½	5	6	7	8	9	10	12 in.
Diameter of flanges	7	8½	9¼	9½	11	12½	13⅜	15	16	18½ ,,
Thickness of flange	13/16	7/8	7/8	7/8	7/8	1	1	1	1 1/16	1⅛ ,,
Number of square holes	4	4	4	6	6	6	6	8	8	10
Centres of holes	5¾	6¾	7½	8	9¼	10½	11½	12¾	13¾	16 in.
Diameter of bolts	9/16	9/16	⅝	⅝	⅝	⅝	¾	¾	¾	¾ ,,
Width of strip	1 1/32	1 1/32	1¼	1⅜	1¼	1⅜	1 5/16	1 7/16	1 7/16	1 9/16 ,,
Thickness of pipe	15/32	½	19/32	⅝	¾	¾	¾	15/16	15/16	⅞ ,,
Length feet	9	9	9	9	9	9	9	9	9	9
Weight cwts.	1 2 0	2 0 0	2 3 0	3 0 14	4 2 0	5 3 0	6 2 0	7 0 14	7 2,2	19 1 14

In the Cornish mines pipes for the same pressure are cast somewhat heavier than those enumerated above.

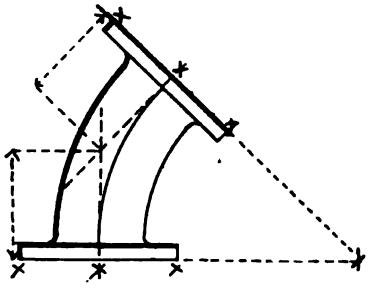


FIG. 38.

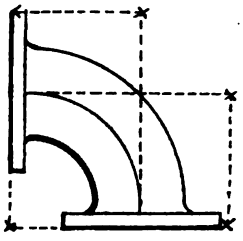


FIG. 39.

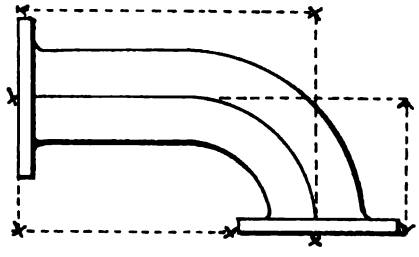


FIG. 40.

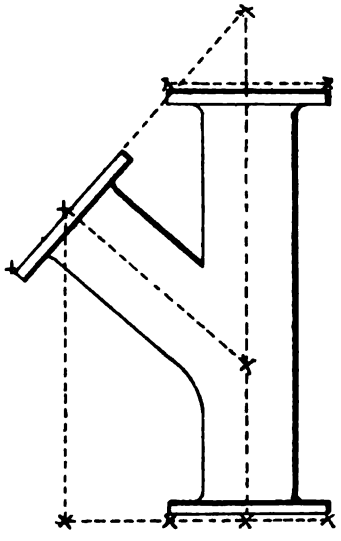


FIG. 43.

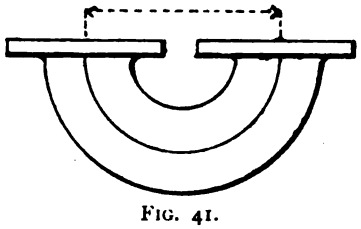


FIG. 41.

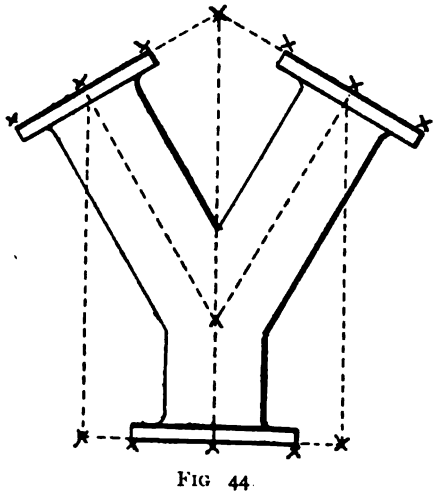


FIG 44

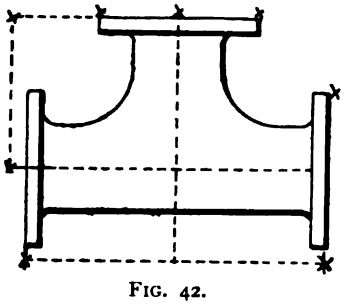


FIG. 42.

Pipe Bends and T and Y Pieces.

Wrought-Iron Pipes.—In foreign mines, as we have already remarked, wrought-iron pipes work out cheaper than cast-iron, and being much lighter are easier to handle; and as wrought-iron has a much higher tensile strength than cast-iron, they afford greater security under 'water-hammer.' Sections of any length can be readily cut and fitted to place at the mine.

'Formerly, column-pipes larger than 14" in diameter for mine use were made of boiler plate, riveted hot, often with butt-joints and lap-strips, the rivets being countersunk on the inside. Now, iron and steel lap-welded tubes up to 24" diameter can be obtained, and manufacturers are preparing machinery for sizes up to 30" in diameter. Welded pipes are either lap-welded or butt-welded. The latter should be used only for smaller sizes, and for moderate pressure, as they are liable to split open at the weld. Lap-welded tubes or hot-riveted pipes of boiler plate are the only wrought-iron pipes suitable for pump-columns in shafts, and for all purposes where heavy pressures and water-hammer are encountered. . . . Numerous experiments have demonstrated that in properly welded pipes the weld is practically as strong as the rest of the metal.'

FIG. 45.

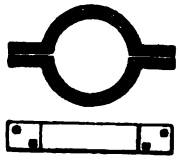


FIG. 45.—Yokes for Pipe Columns.

'Iron boiler plates, including those of which welded tubes are made, have less strength in the direction of their width than their length, which latter is the direction of strain when manufactured into a welded pipe. Sheets of mild steel are homogeneous in this respect, besides possessing greater strength; therefore, for larger sizes steel pipes are nearly always used. Welded pipes may be obtained in lengths up to 20'. For the sake of facility in handling, however, the sections composing a line of pipe in a mine are usually not over 16' in length.'[1]

In cases of long distance shipment the pipe is generally supplied punched, rolled, asphalted, and nested, with necessary rivets. Finished pipe can be nested by making the different sections of pipe of slightly different diameters, as the pressure on the pipe line is greater at one point than at another.

Care should be taken that the thickness is sufficient not only for the required pressure, but for any sudden strain or extra pressure ('water-hammer,' for example), as the bursting of the column pipe might not only cause great damage to the machinery and the shaft work, but also lead to loss of life.

Without considerable increase in the thickness of the metal, the bursting pressure falls rapidly with the increase of the diameter, as we should expect. A 6-inch wrought-iron pipe $\frac{1}{6}$ inch thick has a bursting pressure of 3,800 lbs. per square inch, a 10-inch pipe $\frac{1}{4}$ inch thick (50 per cent. thicker) has only 3,100 lbs. With equal thickness of metal, the bursting pressure of a 10-inch pipe and a 16-inch pipe is 3,100 and 1,930 lbs. per

[1] Hans C. Behr: *Mine Drainage, Pumps, &c.*, pp. 6, 7.

square inch respectively.[1] The flanges are made of either cast-iron, wrought-iron, cast-steel, or malleable iron, and for large pipes are riveted on; for small pipes they may be screwed on.

Steel Pipes.—For pipes of medium and large diameter, particularly where the pressure is great, steel is extensively used. It is admirably adapted for this purpose, being greatly superior to both cast and wrought-iron in strength and capacity to withstand sudden strains and stresses, as well as constant pressures. Its cost, however, prevents its adoption for pipe columns in British mines, cast-iron being so readily obtainable and at such low prices. But for foreign countries where freight and carriage bulk so largely in the total cost, steel should be adopted in preference to wrought-iron; cast-iron pipes are of course out of the question, for reasons which have already been stated.

Very numerous and important experiments have been made in the last half-century by Mr. Telford, Sir William Fairbairn, Mr. Kirkaldy, Mr. Barlow, and other eminent scientists, on cast and wrought-iron and steel, with a view to testing their behaviour under strains and stresses of various kinds, and under a variety of conditions, and thus arriving at their absolute and comparative values for manufacturing and engineering purposes. The following brief summary of results obtained will give the reader a good idea of the comparative value of the metals named for pipe columns and general pump work.[2]

Cast-Iron.—The tensile strength ranges from 5 to 7½ tons per sq. inch, according to the quality and variety of the iron, the best brands averaging 7 tons. The ultimate tensile strength is increased by repeated remeltings to from 15 to 20 tons per sq. inch, and the compressive to from 70 to 80 tons. The transverse strength is very low: assuming a tensile strength of 7 tons per sq. inch, the transverse strength, according to Mr. E. Clark, of a bar 1 inch square 54 inches long, loaded at the middle, is ·252 ton; a bar 3 inches wide × 2 inches deep, same span, gives 2·410 tons. Mr. Hodgkinson found that bars of Carron No. 2, with a span of 54 inches, averaged as follows: 1 inch × 1 inch ·219 ton, 1 inch × 3 inches 1·736 tons, 1 inch × 4 inches 4·600 tons. A 10-inch pipe, ¾ inch thick, having an ultimate tensile strength of 7 tons per sq. inch, is burst at a pressure of 2,192 lbs. per sq. inch. The compressive strength is from four and a half to about seven times the tensile strength. For general calculations the latter may be taken at 7 tons, and compressive strength 49 tons.

Wrought-Iron varies from 22½ to 30 tons, according to the quality and variety, in tensile strength. The elastic tensile strength of iron plates is generally from 55 to 60 per cent. of the ultimate strength. Whilst cast-iron possesses practically no elasticity, and fractures suddenly, wrought-iron and steel stretch appreciably before the breaking point is reached.

As an example of the resistance of wrought-iron to bulging stress, under a pressure of 25,000 lbs. (nearly 11¼ tons) discs 12 inches in diameter

[1] Hans C. Behr: *Mine Drainage, Pumps, &c.*, p. 7.

[2] D. K. Clark, M.I.C.E., &c.: *Rules Tables, and Data for Mechanical Engineers.*

were deflected from ·35 inch for thickness of ·625 inch to ·82 inch for ·440 inch thick.

Steel has a wide range of values in respect of strength. In experimenting with nine specimens of steel, containing different proportions of carbon, Mr. T. E. Vickers found the breaking-weight varied from 30·4 to 69 tons per square inch. Mr. D. Kirkaldy found the average tensile strength of round steel bars (cast steel for tools, blister steel, and puddled steel) to be 42·66 tons. Excluding the specimens of the last-named kind, which give comparatively low figures, the average strength was nearly 50 tons, the tool steel averaging over 59 tons; steel plates from 32 to 45½ tons. Mr. Kirkaldy observed that tool steel was elongated 5 per cent. of its length, some kinds as much as 18 and 19 per cent., and the average 11 per cent. The average tensile strength across the fibre was 91 per cent. of that in the direction of the fibre. Mr. Kirkaldy discovered that the strength of steel was materially increased by hardening the metal in oil; and that it was materially reduced by hardening in water. Three pieces from a bar of chisel-steel were so treated, with the following results:—

	Tensile strength
Soft steel	54¼ tons
„ cooled in water . . .	40¼ „
„ cooled in oil	96⅛ „

The tensile strength of steel plates was found by the same investigator to be as follows:—

Breaking weight per sq. inch, with fibre			42·10	tons; across fibre		43·00	tons
„	„	„	42·97	„	„	43·37	„
„	„	„	36·48	„	„	38·90	„
„	„	„	33·75	„	„	30·84	„
„	„	„	45·28	„	„	37·93	„
„	„	„	45·80	„	„	38·11	„
The average of twelve specimens was			40·17	„	„	36·56	„
The average elongation in parts of length			8·2		„	7·6	

Sir Joseph Whitworth tested iron and steel by the explosive force of gunpowder. The specimens were cylinders having a bore of ¾ inch, a diameter outside of 1¼ inches, and a length of 4 inches. They were made open at the ends, and were closed for the purpose of the experiments.

Metal	Charge of powder		Expansion in diameter at middle, before bursting	Number of pieces when burst
	grains	ratio	inch	pieces
Cast iron	15	1	·0000	36
Wrought iron, Staffordshire (coiled)	95	6·3	·0997	5
Fluid compressed steel, no. 3, red .	275	18·3	·1659	2
„ „ „ „ brown	325	21·7	·0950	4[1]

[1] D. K. Clark, M.I.C.E., &c.: *Rules, Tables, and Data for Mechanical Engineers*, pp. 562, 563, 585, 593-594, 622-624, 691, 694.

We gather from this and other experiments that have been made that for resistance to bursting pressure in a pipe column, such, for example, as 'water-hammer,' wrought-iron is 6 times stronger than cast-iron, and steel is from 3 to $3\frac{1}{2}$ times stronger than wrought-iron, or from 18 to 21 times stronger than cast-iron. We have seen from the examples given that steel, the more finished product of the smelter's art, is greatly superior to wrought-iron and incomparably excels cast-iron in all the attributes of a metal.

Pipe Joints.

Great attention should be given to the joints of the pipes of long lifts, as without a suitable joint there is likely under great pressures to be a

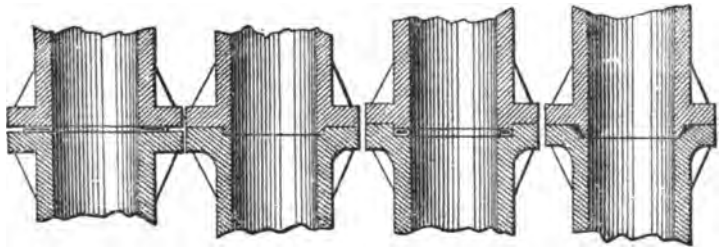


FIG. 47. FIG. 48. FIG. 49. FIG. 50.

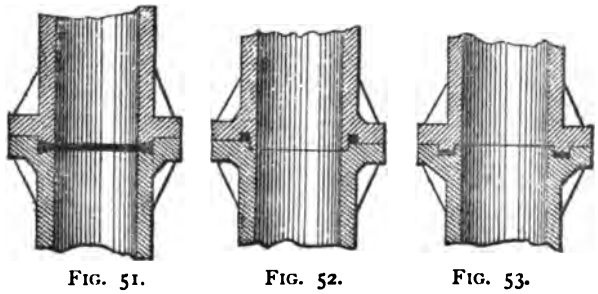


FIG. 51. FIG. 52. FIG. 53.

Pipe Joints.

leakage. In Cornish mines, where the lift rarely exceeds 300 feet (equal to a pressure of about 130 lbs. per square inch at the bottom), the joint shown at fig. 47 is quite sufficient. The unfaced ends of the flanges are brought together, with a thin iron ring covered with tarred flannel inserted between them, and bolted in the ordinary way. If the flanges be faced they may be made to set so exactly that no rings are needed. A more elaborate joint, fig. 48, is sometimes used in Cornish lifts in collieries. A similar joint is shown at fig. 49, which is used for the pipes of the 'Universal' steam-pump. A lead ring, wrapped around with lamp-cotton, without tar, is bolted between the two flanges. They have been tested to 500 lbs. per square inch, or say 1,100 feet head of water. Another joint used occasionally for the same pump is that of fig. 50. One pipe is

recessed, or 'bell-mouthed,' as one says in the North, and the other has a projecting ring to fit the bell-mouth, which is chamfered at the top, as shown by the black part. A round cord of gutta-percha is cut off to the required length to go round the pipe, indicated by the black, and the ends are melted together by a piece of hot iron, thus forming a ring. When the flange bolts are tightened, the gutta-percha is squeezed into the shape shown in the sketch.

Sir William Armstrong has, with great advantage, made his joints, which have to stand a pressure of 700 lbs. per square inch, as shown in fig. 51. A cord of gutta-percha, shown in black, is inserted between the pipe flanges, the lower of which is recessed, and the upper has a corresponding rim or projection. The pressure of the bolt squeezes the gutta-percha flat. It will be noticed that the rim is slightly bevelled, the inner edge projecting beyond the outer. Sir William Armstrong has laid down miles of pipes with this kind of joint, without testing them.

At Nixon's Navigation Colliery, South Wales, this kind of joint is used in connection with the 'Differential' pumping-engine. It is used almost exclusively for heavy pressures by Messrs. Hathorn, Davey & Co., of Leeds. The gutta-percha ring is also used for making the joints of valve-box covers; the ring adheres to the cover, and the latter may be taken off and replaced almost any number of times without requiring a new ring. In the joint shown in fig. 52, it will be noticed that the flange of the upper pipe terminates in a nipple or projection, with a groove turned around it. An india-rubber ring is put into the groove. The flange of the lower pipe has a recess turned out to correspond with the projection in the upper flange. In fig. 53 the india-rubber is placed in a groove in the lower flange.

Pump-Valves.

The pump-valves act a most important part in the action of the pump. Indeed, their function is a most vital one, and they may fitly be described as the 'lungs' of the pump.

The valves must be adapted to the pump, and the circumstances under which it is used. Besides the local conditions under which the drainage operations are carried out, the height of the lift, the quality of the water, the speed at which the pump is worked, and the type of engine, are factors which must be carefully taken into account in designing and applying valves.

The A. S. Cameron pump-valves are made of a casing of brass filled with india-rubber. The latter forms the valve face, and the metallic casing resists the pressure and protects the rubber from injury.

In the various types of Tangyes' 'Special' pump different kinds of valves are used, dependent on the nature of the service. In one variety there are multiple brass valves, with brass seats, moving between guide plates of the same metal, and fitted with brass springs. Cast-iron or brass

clack-valves, brass wing-valves, spindle-valves of the same metal, and india-rubber disc-valves are other types used in the Tangye pumps.

The 'Knowles' pump is provided with valves consisting of best vulcanised rubber or other material, and the valve-seats are independent plates of gun-metal composition.

In the Worthington pumps the valves are of the multiple class, small discs of rubber or other suitable material with metallic springs to assist in closing. In other types the valves are of brass, faced with leather, guided from below by wings, and controlled by composition springs, held in place by the valve-box covers. The valves are arranged in a series of valve-boxes or pot-chambers, each chamber containing one or more small valves having a low lift. The seats are forced into place on a slight taper. Gun-metal valves of the mushroom type are used in some pumps.

Further consideration is given to this subject at p. 311.

Steam Pressure; Exhaust; Condensation.

The motive power for operating the pumps is produced at the surface and led down the shaft to the pump in pipes; only in a very few instances has steam been generated in a boiler underground, near the pump. Even if it were generally possible, which it is not, to place boilers underground, the objections to so doing are both numerous and weighty. In this connection we cannot do better than quote Mr. Behr:—

'It is not often possible to place steam boilers underground, as they require large excavations, around which the ground must be well supported; the smoke and waste gases must be led to the surface; the fuel must be brought down, and the ashes raised or transported; generally, also, the mine water is unfit for boiler use, and suitable water has to be led down from the surface. For these reasons underground steam pumps are nearly always supplied with steam by means of pipes leading from boilers located at the surface.'[1]

We will add to the obstacles and objections named the intolerable heat generated, and the danger in fiery collieries of having boilers in or near the workings.

The pressure of steam at which a pump may be worked is dominated by three factors, namely, (1) the work to be accomplished, (2) the relative size of the steam-cylinder and pump, and (3) the strength of the machine. The maximum pressure for pumps for 'heads' up to 300 feet is rarely allowed to exceed 50 lbs. per square inch, 30 to 40 lbs. being the usual pressures; for 'heads' of from 600 to 1,000 feet the steam-pressure is not run up beyond about 80 to 90 lbs., and often does not exceed 70 lbs.

It is quite obvious that when more work is thrown upon the steam-piston, by the removal of the pump to a lower level, there must either be a reinforcement of energy, by increasing the pressure, or a fresh pump must be requisitioned, in which the difference in size between the steam-cylinder

[1] H. C. Behr: *Mine Drainage, Pumps, &c.*, p. 120.

and pump-cylinder shall be greater, and it may be advisable to moderately raise the pressure of the steam.

Pumps are made strong enough for a certain maximum 'head' of water and steam-pressure, and they should not be worked, except in an emergency, beyond the maker's specified limit. The pump should be ordered of a greater capacity than the present requirements demand, so that there may be a reserve of power available for future developments, the steam meanwhile being throttled.

The tendency of modern engineering practice is for high ranges of steam-pressure, pumps now being built to stand much greater pressures than was customary a dozen years ago.

The following extracts from Messrs. Tangyes' catalogue will be instructive, as showing the different ratios of steam and pump-cylinders for lifts of 300, 600, and 1,000 feet respectively: the size of the steam-cylinder is the same in each case.

300 ft.	Dia. steam cylinder, ins.	26	26	26	26	26	26	26	26	26	26
	,, pump ,, ,,	9	10	12	13	14	15	16	17	18	20
600 ft.	,, steam ,, ,,	26	26	26	26	26					
	,, pump ,, ,,	7	8	9	10	12					
1,000 ft.	,, steam ,, ,,	26	26	26							
	,, pump ,, ,,	7	8	9							

From this, which doubtless represents the best practice of leading makers, we observe that whilst for a small 'head' of water it may be permissible, with an increase in steam-pressure which need not be excessive, to allow the water-cylinder to approximate so closely to the steam-cylinder as 20 to 26, in a 600 feet 'head' the ratio is 12 to 26, whilst in a 1,000 feet 'head' it is 9 to 26. Approximately, the ratio between the diameters of the steam and water-cylinders for lifts from 900 to 1,200 feet would range from 3 to 1 to 4 to 1.

Generally a troublesome problem and one not always satisfactorily solved, is the disposal of the exhaust steam. To make the water in the sump the receptacle for it is, in the case of acidulous water, to seriously increase the corrosive effects of the water on the pump and pipes. If the exhaust is not condensed, but allowed to diffuse itself in the workings and shaft, it makes them in many instances intolerably hot, and the din of the steam in exhausting is often very annoying.

There are various ways of dealing with exhaust steam; namely:

(1) To discharge it into the atmosphere.

(2) To conduct it to the surface.

(3) To condense it into the suction-pipe.

(4) To use an independent condenser.

The first plan, unless the pump be in the shaft or in very close proximity to it, is not permissible; the second method, except at a

moderate depth, is not practicable, owing both to the cost involved and the great back-pressure. The objection to the third plan has already been stated, but where the water is free from acid this method of condensation is very convenient and suitable; the appliance takes up very little space, costs very little, is easily applied, effectually removes a serious objection to the use of this class of pump, and produces an appreciable vacuum, thus increasing the power of the engine. The primary use, however, of this form of condenser is simply to get rid of the exhaust steam. The condenser is attached to the suction-pipe close to the pump. When the suction lift is considerable this condenser facilitates the charging of the suction-pipe, and, therefore, the starting of the pump in cases where it is undesirable to use a foot-valve.

The steam has an injector-like action on the water, and thus increases its velocity. The amount of the vacuum produced is determined by the height at which the condenser stands above the water level.

Air-pump condensers are not usually applied to the class of pumps under consideration unless they are of considerable size and working at a high steam-pressure, the extra room they require making their use impracticable in many of the circumstances under which these pumps are used. The pressure of steam is generally comparatively low, and the limited measure of economy does not sufficiently compensate for the largely increased cost of the engine and the additional room required, the latter consideration in many instances being prohibitive of its use.

This form of condenser will be discussed when dealing with compound engines.

The condenser invented by Mr. Stephen Holman about a quarter of a century ago, and first used in the 'Special' steam-pump, is a good example of a suction-pipe condenser. It is said to produce an average vacuum of about 10 lbs. per square inch on the steam-piston, and it is claimed that it effects a saving of from 20 to 50 per cent. in fuel, and increases to a corresponding extent the efficiency of the engine.

The following is a description of the condenser by the inventor, with a valuable account of its use in the drainage operations at Messrs. Lamb and Moore's collieries at Wigan. Although the examples are somewhat old, the description of the action of the apparatus, the experiments that were made, and the tests applied, are of such an interesting and instructive character, that we make no apology for reproducing the article.[1]

'The condenser, in its general structure, consists of a valve-box, having one or more valves (or deflectors) with single beats, and seats in which are formed annular steam spaces, through which the exhaust steam (at whatever pressure it leaves the cylinder) issues in thin annular streams to meet the water passing over the valve-seats.' Fig. 54 is a section of the condenser.

'In the conducting pipe for conveying exhaust steam from the cylinder

[1] Holman's *History of Draining Mines*, pp. 127 and 128.

to the condenser is fixed a novel arrangement termed a "blow-through" valve, represented in the diagram below (fig. 55), which takes the place of two ordinary stop-valves. The disc-valve at the bottom of the spindle is faced on both sides, and when screwed up closes the outlet to the atmosphere, thus carrying the steam in the direction of the lower arrow towards the condenser. When the pump is first started, it is necessary to exhaust into the atmosphere, in order that the pump, cylinder, and pipes may be fully charged with water before the steam is let in; and this is effected by screwing down the disc, thus closing the way to the condenser, and opening a passage to the atmosphere in the direction of the upper arrow.

'The useful effect will greatly depend upon the proportion of the steam and pump cylinders. Where the former is largely in excess of the latter, the vacuum given on the larger area will be multiplied in its effect upon

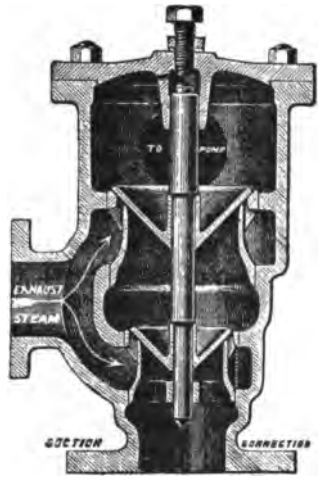


FIG. 54.—Holman's Condenser.

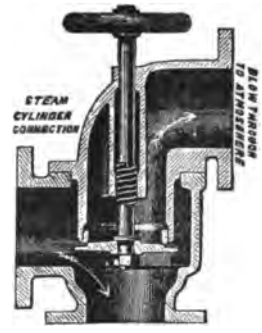


FIG. 55.—Holman's Blow-through Valve.

the other, just as in a steam-cylinder 12-inch diameter we have four times the area of a pump-cylinder 6-inch diameter, so 10 lbs. of steam in the former will be in effect equal to 40 lbs. on the latter. The results due to the condensation of the exhaust steam are practically affected by ever-varying conditions of work. The following is a report of tests made at Messrs. Lamb and Moore's collieries, Wigan, by Mr. Scarborough, with a pair of 30-inch × 10-inch × 48-inch 'Special' steam-pumps, capable of raising 40,000 gallons per hour 500 feet high in a single lift (under date August 17, 1875) at a piston speed of 100 feet per minute:—

'These engines are raising the whole of our water in from six to seven hours, or, I may say, we collect our whole 24 hours' make of water in a lodge in the workings, from which the engines pump it to bank at night after we have done winding coal. They are raising, when at work, from

40,000 to 50,000 gallons per hour, performing from 14 to 17 strokes per minute, and have Holman's Patent Condensers attached. Our practice, previous to putting down the pumping engines, was to wind the water at night at the two winding shafts, and we cleared by this process our whole 24 hours' make of water in from 11 to 12 hours.

'I have been induced to make a number of careful tests with a view to satisfy myself as to the value of your condensers as economisers of steam, and as to their action, if any, in relation to the quantity of water actually delivered to bank. I will describe the tests I have made for quantity of water actually raised to bank with the condensers in action. Number of strokes performed, at various speeds, ranging from 12 to 25 strokes per minute = 370 = 18½ per minute average. Actual quantity of water delivered = 17,699 gallons = 53,097 gallons per hour (the test for quantity being 20 minutes). The theoretical quantity of water due at 18½ strokes per minute = 57,651 gallons per hour. Quantity of water actually delivered, compared with that theoretically due = 92 per cent. The tests for quantity of water thrown in 370 strokes, at the same varying speeds, during a period of 20 minutes, with the steam exhausting to the atmosphere, yielded exactly the same result, as nearly as I could measure the water. I may here state that, in measuring the quantity of water delivered, I made use, in all cases, of a water-tight lodge or pond, into which the water is discharged from the delivery pipe of the pumps; the height of water being indicated by a scale of inches. The superficial contents of this lodge range from 390 to 483 gallons per vertical inch of water, by scale, and the height to which this lodge is filled in a given time, from a given mark on the scale, I take to be a correct index of the quantity delivered. Having satisfied myself that the quantity of water thrown per given number of strokes was the same, with the condenser on, or exhausting to the atmosphere, the testing of economy was a short and easy task. With the steam supply regulated to produce 12 strokes per minute when exhausting to the atmosphere, 18 strokes per minute were obtained when exhausting to the condensers: thus showing an economy of 50 per cent. With the steam supply regulated to produce a speed of 16 strokes per minute when exhausting to the atmosphere, 22 strokes were obtained by exhausting to the condensers: showing an economy of 38·75 at this speed. These results I have confirmed by several subsequent tests, and I make but little comment on them. If they had been against you, they would certainly have been as plainly stated. They are eminently satisfactory to us, as I do not doubt they are to you, and are thoroughly conclusive as to the advantage gained by the system of condensation. Relative to your inquiry as to the result of our experience of the system of pumping as a whole, I may say that it is really practically economical; we have proved it to be much more so than the system of winding water, even in the actual use of steam; and the saving of labour at the two

winding shafts will, in our case, pay for fully 33 per cent. of the quantity of coal consumed in pumping the whole water.'

An Addendum to the foregoing report was given, under date August 27, as follows:—'As to actual pressures of steam in the cylinders, with the condenser in and out of action, when the engines are running 18 strokes per minute, exhausting to the atmosphere, the steam-pressure in the cylinder is 31½ lbs. per square inch by gauge; at the same speed, exhausting to the condenser, the steam-pressure in the cylinder is 21 lbs. per square inch. When the engines run 22 strokes per minute, exhausting to the atmosphere, the steam-pressure in the cylinders is 36 lbs. per square inch; at the same speed, when exhausting to the condenser, the steam-pressure in the cylinder is 25 lbs. per square inch. Thus we have a corresponding gain indicated by the reduction in the pressure of steam required when exhausting into the condenser, to the increase of speed immediately given by turning the exhaust steam from the atmosphere to the condenser.'[1]

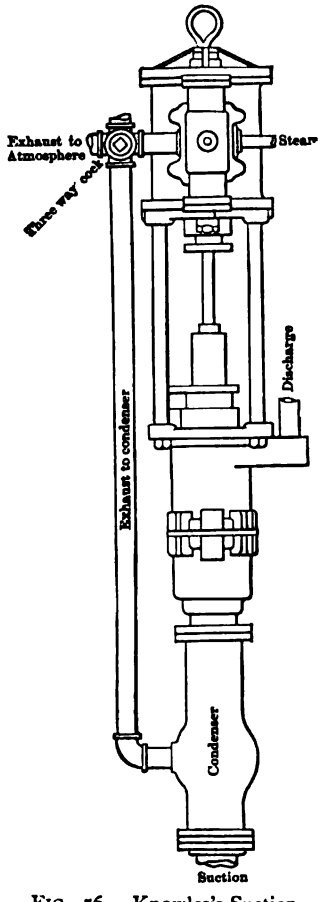


FIG. 56.—Knowles's Suction Condenser.

Fig. 56 is an elevation of Knowles's Improved Suction Condenser.

Considerable loss, of course, ensues from condensation when steam is conveyed great distances. In one instance, which came under the writer's notice, the boiler-pressure of 110 lbs. per square inch was reduced to 102 lbs. in transit to a pump 130 yards distant down a shaft; the steam-pipe was 2½ inches in diameter. If the pipes are thoroughly well jacketed, a much smaller percentage of loss than this results. The temperature of the shaft and workings has naturally some effect on the condensation of the steam. In a colliery there would be a considerable difference of temperature between the upcast and the downcast shaft.

Referring to the Riedler pump located at the 600-feet level in the Leonard shaft of the Boston and Montana Mine, the makers say: 'This pumping-engine is intended to work with steam-pressure of 115 lbs. at the engine . . . the boilers are built to work under a continuous pressure of

[1] Extracted from the *Royal Cornwall Polytechnic Society's Report for* 1875, pp. 76–80.

130 lbs., but it is not believed that the drop in pressure will be as high as 15 lbs. We allow for such an excess of pressure simply in order to have an ample margin, taking into account the deterioration of the boilers in the course of time.'

'Of course, so far as the shaft itself is concerned, much depends on whether it is upcast or downcast. If a furnace shaft, the steam will lose nothing on the way, may even gain something, but there is the inconvenience of making joints or renewing a pipe in a furnace shaft, because the ventilation of a mine has practically to be suspended, and the injurious influence from furnace gases counterbalances any advantage from heating influence. Pipes of a considerable thickness will, under the noxious influence of these furnace gases, be in a few years absolutely eaten away. The writer found that at the bottom of a shaft 400 yards deep the difference in pressure was nearly 10 lbs., and in another case, with a shaft 200 yards, and 600 yards additional in the workings, there was a difference of nearly 20 lbs. although the pipes were covered. This may seem a large reduction of pressure, but steam which has to travel half a mile, and mostly through a very cold and very rapid current, will necessarily be seriously affected.' [1]

RESULTS OF EXPERIMENTS ON THE CONDENSATION OF STEAM IN CAST-IRON PIPES. (M. Burnat.)[2]

Absolute pressure of steam per square inch	Temperatures			Steam condensed per square foot of external surface of pipes per hour				
	Steam	Air	Difference	Straw coat, 1st	Bare, 2nd	Pottery coat, 3rd	Waste coat, 4th	Plaster coat, 5th
Averages 22·0	233·1	36·5	196·6	·200	·581	·229	·286	·324

'When the plaster coat of the fifth group was painted white, an average of 0·307 lb. of steam was condensed per square foot of pipe per hour; and the second group, with the felt coating, condensed 0·313 lb. of steam per square foot per hour.'

'The most effective coat for the prevention of condensation was the straw coat, and it had the effect of reducing the loss by condensation to one-third of that which took place with the naked pipe. With the naked pipe, 2·812 units of heat were transmitted per square foot per degree per hour.'

'In experiments by Mr. B. G. Nichol, a wrought-iron pipe $3\frac{3}{4}$ inches in diameter outside, $\frac{1}{4}$ inch thick, and lagged to half an inch thick with felt and spun yarn, condensed steam at 245° F. at the rate of ·262 lb. per square foot per hour, in an external temperature of 60°, equivalent to 1·26 units of heat per square foot per 1° difference of temperature.'

[1] C. M. Percy: *Mechanical Engineering of Collieries*, vol. ii., p. 141.

[2] D. K. Clark: from *Manual of Rules, Tables, and Data for Mechanical Engineers*, pp. 473, 474.

'According to M. Clément's experiments, the quantities of steam given in the second column below were condensed per square foot of pipe surface per hour, in a temperature of 77° F. Assuming that the steam condensed was of 20 lbs. absolute pressure, the difference of temperature was 151° F., and the weight of steam condensed per 1° F. is given in the third column.'

Surface	Steam condensed per square foot per hour	
	Total	per 1° F.
Bare cast-iron pipe, horizontal .	·328 lb.	·00217 lb.
Blackened ,, ,, .	·308 ,,	·00204 ,,
Bare copper ,, ,, .	·267 ,,	·00177 ,,
Blackened ,, ,, .	·308 ,,	·00204 ,,
,, ,, upright . .	·359 ,,	·00238 ,,

'Here it appears that the blackened surfaces of iron and of copper were equally active; and that the upright pipe condensed more steam than the same pipe laid horizontally.'

'Mr. Grouvelle found that, in a temperature of 60° F., a square foot of pipe heated by steam condensed 0·328 lb. of steam per square foot per hour. Assuming that the steam was of 20 lbs. absolute pressure, the difference of temperatures was 228°—60°=168°F., and 0·0020 lb. of steam was condensed per square foot per 1° F.'

'Summarising the several results above for bare cast-iron pipes:—

Difference of temperature	Steam condensed per square foot per hour		
	Total	per 1° F.	Average
	° F.			
Tredgold . . .	161 .	0·352 lb.	·0022 lb.	
Burnat . . .	196·6 .	0·581 ,,	·0030 ,,	
Clément . . .	151 .	0·328 ,,	·00217 ,,	
Grouvelle . . .	168 .	0·328 ,,	·0020 ,,	
Average, say, for steam of 20 lbs. absolute pressure	169 .	0·400 ,,	·00235 ,,	say $\frac{1}{420}$ lb.

Hutton gives the following:[1]—Steam saved by non-conducting coverings 1½ inch thick, each composition being lapped with paper and canvas outside.

Hair felt, wood-lagged :—	saving over naked pipes	96 per cent.
Slag-wool (silicate cotton)	,, ,,	95 ,,
Fossil meal and hair plaster	,, ,,	89 ,,
Asbestos paste; paper lagged	,, ,,	71 ,,
Asbestos paper; brown paper lagged	,,	68 ,,

At the Drum Lummon Mine, Montana, where a Riedler pump is at work 1,200 feet down the shaft, 'the steam line runs through 1,000 feet of tunnel and then down the shaft 1,200 feet, but condensation is prevented as far as possible by thoroughly covering the pipe with magnesia covering, over which there is a hair-felt covering, and outside of all this is a tin sheet

[1] W. S. Hutton: *The Works Manager's Hand-Book*, p. 112.

soldered on. I may say that this use of tin has proved of great advantage, although it has not been in use very long.'[1] At the Chapin Mine, Michigan, the steam pipe (7 in. diameter) is covered with 3 in. thick carbonate of magnesia.

Sizes and Weights.

These pumps are usually very compact, the two cylinders generally standing upon the same bed-plate. The total length and width of the medium sizes are within 13 feet by 5 feet, and of the small sizes 5 feet by 1½ feet. The largest sizes are imposing engines, extending to 18 feet by 7½ feet. A 'Universal' pump, 7-inch steam-cylinder and 5-inch pump-cylinder, occupies but 4 feet in length, and in height only 13 inches for two-thirds of this length, and 2 feet 8 inches for the remainder.

They vary in size from a steam-cylinder of 1½ inch to 40 inches, and a water-cylinder of 1 inch to 22 inches, and a stroke of from 6 inches to 6 feet. The very small sizes are used for tanneries, chemical works, etc. The smallest pumps used in mines and collieries are from about 6 to 8 inches diameter steam-cylinder, and about 3 inches water-cylinder; even the smallest sizes have been in a few instances used in mines and collieries for feeding boilers or some other surface work of a very light character. A pump with less than a 9-inch steam and a 6-inch pump cylinder would be of little service for underground pumping operations, except for emptying dips where the influx of water is small. Such a pump with a piston, speed of 100 feet per minute, would deliver over 7,000 gallons per hour.

We have already considered in the article on steam-pressure the relative sizes of steam and water-cylinders; it will be sufficient if we now state that any combinations can be made between the cylinders.

The two following tables of the sizes etc. of some of the 'Universal' and 'Excelsior' pumps respectively afford an idea of the dimensions of pumps of this class, of which we think they may be taken as fair examples:

Diameter of steam-cylinder	Diameter of water-cylinder	Length	Width	Weight
in.	in.	ft. in.	ft. in.	tons cwts. qrs. lbs.
4	2	3 0	0 10	0 1 2 20
6	3	3 8	1 5	0 3 2 0
7	6	4 4	1 5	0 6 2 10
9	6	4 10	1 5	0 8 1 14
12	4	8 6	3 6	1 5 0 0
12	12	9 0	3 6	1 18 0 0
15	6	10 10	4 2	2 5 0 0
18	4	11 3	4 2	2 8 0 0
18	12	8 10	3 1	2 15 0 0
18	15	9 6	4 0	3 10 0 0
21	5	12 6	4 6	4 0 0 0
25	4	14 0	4 0	5 0 0 0
30	8	14 0	4 6	8 0 0 0
40	13	18 0	7 6	13 0 0 0

[1] Mr. C. W. Goodale: Letter to Author dated August 26, 1897 The writer does not give the loss of pressure by condensation. [A later letter, Oct. 23, 1898, referring to this is quoted at p. 325, as is also one from Mr. F. Scadden.—S.M.]

Diameter of steam-cylinder	Diameter of water-cylinder	Length	Width	Weight
in.	in.	ft. in.	ft. in.	tons cwts. qrs. lbs.
4	2	3 6	0 11	0 2 1 0
6	3	3 6	1 0	0 4 0 0
7½	6	5 10	1 8	0 11 2 0
9	6	5 10	1 8	0 14 0 0
12	6	5 10	1 8	0 18 0 0
12	12	9 6	5 4	2 15 0 0
16	6	10 0	3 0	2 10 0 0
16	12	10 0	5 4	3 15 0 0

The following dimensions, in inches, of the 'Special' steam-pump, piston type (300 feet series), besides the floor space, give the height of the different sizes and the length over all, if supplied with an air-pump condenser. The weight, in hundredweights, is also given.

Diameter of steam-cylinder	Diameter of water-cylinder	Length of stroke	Length	Width	Height to top of air-vessel	Length over all with air-pump condenser	Weight
7	4	12	54	19	43	91	7½
8	4	12	55	19	43	92	8¼
9	4	12	57	20	45	93	9½
10	4	12	58	21	45	95	10½
12	5	24	89	22	54	152	16½
14	6	24	92	24	57	153	24½
16	7	24	98	29	77	167	37
18	8	24	98	30	82	170	46
21	9	24	108	35	89	178	61
24	9	24	108	36	89	186	69

The following are dimensions (in inches) and weights (in hundredweights) of Duplex piston-pumps (Tangye's 300 feet series).

Diameter of steam-cylinder	Diameter of water-cylinder	Length of stroke	Length	Width	Height to top of air-vessel	Weight
7	4	12	89	32	62	28
8	4	12	90	32	62	29
9	4	12	91	32	62	29
10	4	12	91	32	62	31
12	5	12	95	32	62	35
14	6	12	103	39	76	53
16	7	12	107	39	76	61
18	8	12	113	52	89	84

Speed.

A well-designed steam-engine may be run to any speed up to 750 to 1,000 feet a minute. In engines having a rotary movement, like those for marine and railway locomotion, in which the elastic force of the steam operates upon matter which readily responds, and admits of a high range of momentum, a great speed is quickly developed. Marine and railway engines frequently attain a speed approaching 1,000 feet a minute.

With a reciprocating pumping engine the case is very different. Not only has it to reverse its motion at the end of each stroke, but it has to operate upon an inert incompressible element which comes, in many types of engine, to a state of rest at the end of each stroke. The piston, therefore, at the beginning of each stroke is impacted upon an inert, a ponderous, and an inelastic body, which, within the compass of a single stroke, can only be moved comparatively slowly, unless the ratio of steam to water-cylinder for the head of water is high and there is a high steam-pressure. The momentary pause at the end of the stroke which is essential to good action of the pump-valves involves loss of power by allowing the water to approach a state of rest. Rotary pumps have this advantage, that, admitting of continual motion, they keep up a steady and regular flow of water and can, therefore, be run at a much higher speed than the non-rotary class of pumps, and work with more economy. They are, however, open to the objection stated. The usual speed at which these pumps are worked is about 120 feet per minute for all sizes. Some pumps, if worked very slowly, are liable to stop, owing to the valves getting centred. It is a prime test of the efficiency of direct-acting pumps to endeavour to work them so slowly that the piston crawls along, as it were. The maximum speed of a 4-inch × 2½-inch pump, 6-inch stroke, is 350 strokes per minute =175 feet; a 6-inch × 3½-inch pump, with 8-inch stroke, 300 per minute =200 feet; a 12-inch × 7-inch, 12-inch stroke, 200 per minute=200 feet. To prevent a misunderstanding it will be necessary to explain that we have taken the stroke of the engines to be the travel of the piston from one end of the cylinder to the other only. In the accompanying table the first eight are piston-pumps, and the second eight ram-pumps.

Diameter of steam-cylinder	Diameter of water-cylinder	Length of stroke	Maximum number of strokes per minute	Maximum speed
in.	in.	in.		ft.
3	1	5	350	146
4	2½	6	350	175
4	2½	6	300	150
6	3½	8	275	183⅓
6	3½	8	300	200
8	5	10	250	208⅓
10	6	12	200	200
12	7	12	200	200
8	5	10	200	166⅔
8	6	18	150	225
16	8	30	75	187½
18	10	36	60	180
24	12	48	50	200
30	15	60	40	200
30	15	72	30	180
36	18	72	30	180

We observe from this table that the greatest number of strokes varies from 30 to 350 per minute, according to their length, and the piston-speed

from 146 to 225 feet. This may be considered to fairly represent the greatest capacity of this class. The usual working speed would probably not exceed two-thirds of that given.

Long-stroke engines have certain advantages over the short-stroke, inasmuch as they can be run at a higher speed because the number of reversals is fewer, their durability being proportionately increased, and the smaller quantity of steam necessary, on account of less clearance, for a given piston speed.

As the friction of water through pipes increases in the proportion of the square of the velocity, it is obvious that whilst it promotes economy to keep the water moving, the pump cannot be driven at a high speed without serious loss of power. The speed of water through pipes ought not to exceed 200 or 250 feet per minute, and the area of the pipes should be proportional to the speed. Large engines may be run faster with advantage than small engines, as the loss in friction is much less in proportion to the quantity of water pumped. A speed of 100 feet a minute is quite sufficient for small steam-pumps if an excessive resistance in the rising-main is to be avoided.

Capabilities.

In discussing the merits of this class of pumps, and the particular circumstances and conditions of drainage in which their employment is suitable and advantageous, it will clear the ground and help us in assigning them their position as a pumping agent if we first state the principal objections that are urged to their use.

It is well known that these pumps are not economical in the consumption of fuel; where this is dear it constitutes a serious objection to their adoption. There can be no question as to the superior economy of a surface engine, with its boiler alongside, to a single cylinder engine underground, steamed from surface.

There is more wear and tear, and more liability to derangement and breakdown with these engines, than is the case with surface engines. If the location of the mine be remote from supplies, as it usually is, any necessity for renewals or repairs, unless they can be made with unskilled labour and with little delay, may be attended with serious consequences.

Then there is the objection of carrying steam down the shaft and into the workings, making them uncomfortably, in some instances intolerably, hot. In deep mines the temperature is too high to permit of any appreciable increase of it if it can possibly be avoided. Another objection is the risk of these pumps being 'drowned' and the mine consequently flooded. The latter misfortune can, in many cases, be provided for by duplicating the engine on the American principle, using the lower pump at or near the sump, and pumping up to the other pump, located in a station, or by having a large reservoir capable of storing two or three days' supply of water.

Mr. Henry Davey refers to a case of a colliery drained by thirty under-

ground steam-pumps becoming flooded by a sudden influx of water too great for the pumps to suddenly deal with. The pumps stopped one after another, and the colliery became flooded, and remained so until new surface engines could be procured. The unwatering was done by means of four 24-inch suspended sinking lifts, each 300 feet long.[1]

The duplication of the pumping plant, and the providing large storage reservoirs, would entail serious additional cost, and would, to that extent, discount, in the matter of capital outlay, one of the principal claims for the use of underground engines. Moreover, it would not be always practicable to excavate such reservoirs.

'The objection to the system is the danger of the machinery being "drowned," and so rendered useless, by an unusual influx of water, because a mishap of this kind would involve the erection of new pumping plant for draining the mine.'[2]

Compressed air may be used, but this is still less economical than conveying down steam. Unless compressed air be required for working drills, coal-cutters, etc., or for winding, it is an expensive way of draining mines, and should never be resorted to where economy is a desideratum. Not only must a compressing plant be provided, but there must be an engine to operate it, and, as in the case of steam, the air must be conveyed down to the pump. The useful effect is very low, and the expense is great.

According to Dr. Siemens, the attainable limit of the useful effect of compressed air is about 50 per cent. of the power exerted in compression. Professor Rankine says that the loss of power seldom amounts to less than from 65 to 75 per cent.

'Compressed air has been used to work coal-cutting machines at Messrs. Baird's works at Gartsherrie. In this case 2½ cubic feet of steam, at 40 lbs. pressure, gave 1 cubic foot of air at 50 lbs. pressure. Compressed air has been used since 1864 in the shops of Messrs. Eastons and Anderson at Erith, where the consumption of coal necessary to produce a given quantity of compressed air was found to be about 69 per cent. more than to produce the same quantity of steam at a like pressure.'[3]

Mr. D. K. Clark says that 'in general practice the resultant efficiency of air-compressing plant rarely exceeds 30 per cent. The less the degree of compression the greater is the efficiency, because the less is the proportional loss from the intermediate reduction of temperature.' Comparing the efficiency of compressor and motor where the compression is carried to ten atmospheres, with plant compressing to two atmospheres, he figured out the former to be 33 per cent. and the latter 52 per cent. of the power employed.[4]

[1] Henry Davey, M.I.C.E., *On Water in Deep Shafts*, a paper read at Conference of Institute of Civil Engineers, May 25, 1897.

[2] C. Le Neve Foster, D.Sc., F.R.S. : *Ore and Stone Mining*, p. 466.

[3] H. Robinson, M.I.C.E. : *The Transmission of Motive Power to Distant Points.*

[4] D. K. Clark, M.I.C.E. : *Manual of Rules, Tables, and Data for Mechanical Engineers*, p. 911.

Steam-pumps have in a few instances been used underground in Cornish mines, notably at Dolcoath mine, near Camborne, where a 'Special' pump of 5-inch steam cylinder, and $2\frac{1}{2}$-inch water cylinder, and 10-inch stroke, was introduced several years ago. It was used about a year to drain a winze from the 338 to the 352 fathom levels, and was worked with compressed air of about 50 lbs. per square inch, supplied by a powerful compressor constructed by the Perran Foundry Company, from the designs of Mr. Loam, for working the boring machines. A steam-pump supplied to East Pool Mine, and intended for service underground, was only used for lifting water from the compressor to the engine pond. A pump of this class was also used at Levant Mine, in the submarine part.

Whilst these trials cannot perhaps be held as conclusive of the suitability or otherwise of these pumps for use in the Cornish mines, it is significant that they were in use in each case only a comparatively short time, and that although nearly twenty years have elapsed since the trials were made, the author is not aware of another instance of their use underground in Cornwall.

The circumstances which militate against the adoption of these pumps in these mines are such as, in their number and magnitude, are perhaps not present in any other mining district. First and foremost is the great cost of fuel. Coal delivered on the mines varies from 14*s.* to 15*s.* per ton, according to the distance from the port and railway.[1] Not only is the mineral comparatively very poor, but generally it is mined at great depths and the mines are as a rule heavily watered; the margin of profit, therefore, is generally so small that the utmost economy has to be studied *inter alia* in pumping. The factories for producing the engines so renowned for their economy are, as it were, on the spot, and repairs can be effected in a very short time. The water is usually strongly acidulous, and often carries grit and gravel (which, from the nature of the rock, are very hard), and consequently would be very destructive to the pump-piston, cylinder, and valves. Steam-pump works are so remote that, unless reserve pumps and duplicate parts were kept ready for immediate use, a breakdown would entail a serious inundation, so rapidly does the water rise; and as generally the most valuable workings are the deepest, a great loss would be entailed by a prolonged submergence of the ore deposits. A steam-pump in a Cornish sump during sinking operations is, perhaps, in as rough and trying a situation as can be imagined. To all these adverse influences we may add the prejudice in favour of the Cornish engine, of which the engineers are so justly proud. It is, therefore, hardly conceivable that any other form of pumping engine than the Cornish, or a modification of it, will ever be used in the Cornish mines.[2]

[1] The quality generally used is known as 'Thro' and Thro' Mining Coal,' a semi-bituminous Welsh coal, 25 to 35 per cent. large, shipped principally at Neath Abbey. The prices given are those ruling immediately anterior to the recent strike of the Welsh colliers: the cost of cartage from the railway siding to the mines is included.

[2] A competitor on Cornish soil has lately entered the lists against the Cornish engine

It remains to be seen whether a further trial of steam-pumps, as auxiliaries, will be made, but the results of the attempts named were certainly not likely to encourage further experiments in this direction. In the following remarks Mr. N. Trestrail undoubtedly voices the opinion of leading Cornish engineers. After stating that there are no steam-pumps underground in the county, he says: 'I am perfectly sure it is not desirable to adopt them. Air-winches and small engines are frequently used in our mines for winding dirt, and drawing water from winzes or sumps. In deep mining the difficulty is to keep the mine properly ventilated; driving what appliances may be required underground with compressed air helps to serve that purpose, but to carry steam underground is a very great mistake.' [1]

The late Mr. William Husband, not only a distinguished engineer, but a manufacturer of Cornish engines, held the opinion, as we shall presently see, that pumps of this class might be used with advantage as auxiliaries to the large engine.

Mr. John Pratt, superintending engineer of the Real del Monte Mining Co., Mexico, has informed the author [2] that the experience with steam-pumps in some of the mines in that country has not been satisfactory. In the San Rafael mine plunger-pumps, outside-packed, were used, but were found not to be at all adapted to sinking, and the steam (taken down from the surface) made the workings very hot. The mine was soon flooded and the pumps 'drowned.' These will be discarded, and a new plant installed. The almost universal practice in the Mexican mines, many of which are heavily watered, is to use the Cornish engine. The results of the few attempts to employ steam-pumps have not been such as will be likely to disturb this supremacy.

Referring to the mines in the province of Cordova, Spain, Mr. S. S. Whitburn states: 'In every mine where there is a promise of permanency we are putting up the old-fashioned Cornish pumping engine, and ordinary Cornish lifts with clack-valves. I should say that on deciding upon the most suitable engines for pumping purposes places and circumstances should be first taken into consideration. Where coals are dear, a cheap labour market, suitable building material close at hand, easy transport for heavy machinery, etc., I think it will take a lot yet to beat our old friend the Cornish Beam Engine and Cornish Lifts for metalliferous mines, and

in the Davey Compound Surface Engine recently erected at the Basset Mines, near Redruth, the performance of which will be keenly watched by the Cornish engineers and mine managers. It is a vertical engine with high and low-pressure cylinders of 40 and 80 inches diameter respectively, working a single pump-rod with a 13-feet stroke. The stroke of the high-pressure piston is 9 feet and that of the low-pressure 10 feet. The pressure of steam will be 150 per square inch. The pitwork has been designed by Mr. N. Trestrail, to whom the author is indebted for the foregoing particulars. This is not the first attempt to introduce the principle of compound cylinders in Cornish mines; Woolf in 1814, and Sims in 1840 essayed this, but failed in competition with existing engines, owing to using steam of too low a pressure.—S.M.

[1] Letter to Author, dated November 30, 1897.

[2] An interview, July 16, 1897.

where there is a large quantity of water to deal with. I have heard of Belgian, German, and other kinds of engines being tried in this country and other places where I have been, but none seem to be attended with the same success as the Cornish Beam Engine. These mines (the Demetrio) are about 120 miles from Seville; the cost of coal delivered on the mines is from 15*s.* to 20*s.* per ton, according to quality.'[1]

The following observations on the pumping methods in the mines of the Transvaal by Mr. James Whitburn, of the Henry Nourse Gold Mining Co., Doornfontein, near Johannesburg, are also of much interest and value: 'For vertical shafts, provided there is sufficient room, the Cornish Pump of the type supplied by Messrs. Harvey & Co., without any particular modification, meets with general approval. There have been several small alterations introduced, but they do not make any headway. Other classes of pumps are principally introduced for the sake of first cost, owing to insufficient room in the shafts, or for speed in getting out water at a comparatively small cost (capital outlay).'

'The description of pump used varies according to the opinions of different persons, and sometimes depends upon what can be obtained in the market, from the single and double cylinder steam-pump manufactured by Tangye, and other pumps of similar type, to the electric pump driven by motors. In sinking, in cases where the inflow of water is very large, the Cornish Bucket Pump is the best; but where there is a less quantity to contend with, the steam sinking pump is very often used.'

'Where compressed air is available, pumps driven by it for sinking are very useful, for there is no heat produced, and they cause extra ventilation, and the pipes are not cumbersome. The Electric pump is too delicate for sinking purposes generally.'

'The pumping plant at the Henry Nourse Mine consists of a single cylinder horizontal non-condensing engine, cylinder 16 inches diameter, stroke 32 inches, by Ruston, Proctor, & Co., at the surface, operating Cornish pump lifts through the intermediary of connecting-rod and balance beam.'[2]

In the Cripple Creek Mines, Colorado, much trouble has been experienced in sinking with steam-pumps. Mr. E. Skewes states it was necessary to have an engineer on the spot when sinking; the grit did much injury to the valves, and derangements were of frequent occurrence.[3]

We have stated candidly, and we trust fairly, the principal objections to the use of these pumps underground, conditions and circumstances prohibitive of their adoption, and given expression, generally in their own words, to adverse criticism from some competent mining authorities. We will now consider what can be advanced on their behalf, and their claims to the consideration of mining men, giving, as in the former case, the opinions

[1] Letter to Author, dated August 30, 1897.
[2] Letter to Author, dated August 20, 1897.
[3] Interview, May 31, 1897.

and experiences of practical men. Examples of good work done by these pumps will also be given.

At the Empire Mine, near Antioch, California, where the water was strongly impregnated with sulphuric acid, a 'Knowles' steam-pump has done excellent service; dimensions 24-inch steam-cylinder, 10-inch plunger, stroke 24 inches. Steam was piped down the shaft 450 feet in 3-inch pipes. The quantity of water handled was about 250,000 gallons in 24 hours. Speaking of the performance of this pump Mr. John T. Cox says it is 'as fine a pump as was ever made.' A Stoddard pump was used 'for a change over,' and also did good service.[1]

Mr. Frank Scadden, of the Columbia, Lamont, Paint River, and Mansfield Mines, Michigan, makes the following interesting remarks: 'In our mines we make a "sump" or "fork" to hold, say, 15,000 or 20,000 gallons, and set our pump at this spot, and concentrate all the water at this point by means of ditches, siphon pipes, etc.; we find this the cheaper way. Very few mines in this section of the country hold any water in the upper levels; the ground is a black slate or sandstone, and is porous, consequently the upper levels are dry, the water concentrating at the lower ones. We use steam-pumps exclusively in our mines; they are easiest to handle, can make repairs more quickly, the parts are smaller, and they do the work necessary. We notice that some of the mines that put in Cornish pumping engines went back to steam-pumps, the machinery had to be so ponderous, and the limited amount of water in many cases made it difficult to keep them in order. At Mansfield we are handling the water in a similar manner to Columbia mine; we started with single pumps, but found it used less steam to work a duplex, and for deep mining we find compound (*i.e.* twin) triple expansion saves considerable fuel—about one-third over the straight line.'

'The pumping plant at the Columbia Mine is as follows: Duplex steam-pump, 18 inches steam by 8-inches water-cylinders, 18-inch stroke, worked at from 55 to 62 strokes per minute. Pressure of steam 80 lbs.; water lifted 550 feet.'[2]

'At the Gagnon Mine, Butte, Montana, we have a compound condensing Duplex Knowles pump on the 1,000 feet level, which throws the water to the surface. The capacity is 300 gallons per minute, although the amount of water in the mine is only about 100 gallons. It has been a very satisfactory pump.'

'The Palmer pump, which was introduced in Aspen, Colorado, has given, I understand, good satisfaction in sinking shafts.'[3]

Drainage operations in the gold mines of British Columbia are generally on a small scale. The following description of the pumping plant at the Le Roi Mine, in the Slocan district, has been supplied by Mr. A. G. Coryn:

[1] Letter to Author, dated August 18, 1897.

[2] Letter to Author, dated July 15, 1897. [A later letter, October 25, 1898, is quoted at p. 325.—S.M.]

[3] Mr. C. W. Goodale; letter to Author, dated August 26, 1897.

'On account of the small amount of water the drainage system is not an extensive one.[1] During 24 hours there are about 5,000 gallons gathered in the sumps or tanks, mostly coming from upper levels. On the 500-foot level there is a station pump, Cameron's double plunger type, 10 × 5 × 10,[2] with 4-inch discharge; this up to a few months ago handled all the water coming into the mine. Recently a Knowles station-pump, also a double plunger 14 × 7 × 12, with 5-inch discharge, has been installed on the 600-foot level. In addition to these there are two No. 7 Knowles sinking-pumps, used for sinking, in the main shaft and winze. They are properly bulkheaded and lowered from time to time as required. The pumps are all run with compressed air, one engineer having charge on each shift.'[3]

Reference has been made to the late Mr. William Husband. His views are specially interesting and valuable from the position he held of managing director of works celebrated all over the world for the manufacture of Cornish engines, and his high reputation as an engineer. He held the opinion that steam-pumps might be advantageously applied as auxiliaries to the more economical Cornish engine. The following are his words: 'In sinking wet shafts considerable difficulty is frequently experienced in keeping the sump clear of water so as to allow the men to work. In fact, where the water is quick and the lifts large, a considerable quantity must always accumulate in the bottom of the shaft, although the holes in the windbore be plugged low down, and the power required to draw the water through the contracted water-way thereby be injuriously increased. Under such circumstances the operation of sinking would be greatly facilitated, and the strain on the pump-work diminished, by the employment of a small auxiliary pump, to run about 20 or 30 strokes per minute, and lift the water into a cistern about three or four fathoms above the bottom of the shaft, the main pump to lift the water from this cistern. The auxiliary pump could be driven by compressed air, which might be obtained by a compressor worked off the main rod, or by other means. Should the shaft be sunk by boring machinery, compressed air would be available for the purpose; a flexible suction-pipe might be employed for the auxiliary pump, which could be easily handled and removed when blasting.'[4]

The 'Special' steam-pump at the Adelaide Colliery, Bishop Auckland, with a 26-inch steam-cylinder, 6½-inch water-cylinder, and 6-feet stroke, discharged 8,000 gallons per hour to a height of 1,040 feet in one direct lift.

A 'Special' pump supplied to the West Yorkshire Iron and Coal

[1] The British Columbian miners are fortunate in having in some of their districts a thick impermeable boulder clay which keeps out the surface water (*vide* 'Annual Report of Minister of Mines, British Columbia, for the year ending December 31, 1897,' pp. 471, 493).

[2] Ten-inch steam cylinder, 5-inch plunger, 10-inch stroke.

[3] Letter dated March 12, 1898.

[4] *Proceedings of the Mining Institute of Cornwall*, vol. i. No. 5, p. 168.

Co., near Leeds, raised 16,000 gallons per hour 465 feet in one lift. At the Gosforth Colliery, Newcastle-on-Tyne, a pair of 32-inch engines of the same type, working 7-inch pumps, with 6-feet stroke, will raise 18,000 gallons per hour 1,068 feet, with a steam-pressure of 35 lbs. per square inch.

At the Foxhole Colliery of the Patent Anthracite Coke Co., Swansea, a 'Universal' pump of 21-inch steam-cylinder and 6-inch water-cylinder has been in use pumping 3,500 gallons per hour 400 feet vertically; steam-pressure 40 lbs.

Three 'Universal' pumps at the Gelli Colliery, Rhondda Valley, have done the following work:—1st pump, 352 yards down the slant, 12-inch steam-cylinder, 6-inch water-cylinder, raises 10,000 gallons per hour 117 feet through 485 yards of pipe—steam on boiler at surface 40 lbs.; 2nd pump, 12-inch steam-cylinder, 6-inch water-cylinder, lifts 18 feet vertically through 120 yards of pipe—steam carried 494 yards; 3rd pump, 15-inch steam-cylinder, 7½-inch water-cylinder, raises 17,000 gallons per hour to a vertical height of 156 feet through 388 yards of piping—steam carried 406 yards. In all cases the exhaust steam was condensed.

At the Yate Collieries, near Chipping Sodbury, a 'Universal' has lifted 2,500 gallons per hour 480 feet, at 30 strokes per minute, with steam-pressure at 30 lbs.; boiler 340 yards from the pump; the size of the pump was 15 inches by 4 inches.

The value of these pumps in an emergency, such as the flooding of a mine, was strikingly demonstrated in the terrible inundation of the Tynewydd Colliery in April 1877, when pumps of the 'Special' type were the chief means used to overcome the vast body of water which had burst in upon the workings from an adjoining mine, and without which the rescue of the entombed men would have been impossible. Some account of the action of these pumps at the above-named colliery, visited by the author a short time after the accident, will be useful as showing their value in a disaster such as occurred there. The 6-inch bucket-lift in use prior to the accident for draining the dip workings was choked, and could not be set to work. A 'Universal' pump lent by the Havod Colliery was immediately taken down the pit, and fixed near the water-level. It had a steam-cylinder of 12 inches and a water-cylinder of 6 inches, with a 14-inch stroke. It was run to an average of 80 strokes per minute, the greatest speed being 120 strokes. This pump was thrown aside on the arrival of a larger and more efficient 'Special' pump from the Llwynypia Colliery, and which became the main instrument in clearing the dip. It had a steam-cylinder of 12 inches and a water-cylinder of 10 inches with an 18-inch stroke. It was worked at an average speed of 40 strokes per minute, the greatest speed being from 45 to 50, and the lowest 35 strokes. At the bottom of the pit, which is 88 yards deep, was another 'Special' pump assisting a Cornish double-plunger lift of 12 inches diameter and 3-feet stroke, worked by a large water-wheel, to raise the water pumped into the sump by the steam-pumps above described. The 'Special' in the dip worked without intermission, save lowering it twice to keep it near the water

(the 'Universal' being worked whilst these removals were being made), 12 days, pumping about 50 tons (11,000 gallons) per hour. The 'Universal' worked three days, pumping about 30 tons (6,700 gallons) per hour.

These pumps were supplied with steam by two locomotive boilers in a roadway on a level with the top of the dip and the bottom of the pit. The top of the dip is 720 yards from the pit, and extends to about 143 yards, at an average inclination of about 5½ inches to the yard. The highest point reached by the water was about 3⅛ yards vertically from the roadway. The large 'Special' pump in the pit, capable of lifting 13,000 gallons per hour, was supplied with steam from a locomotive boiler at the surface, which supplied the steam at 110 lbs. per square inch, and it was used at 102, 8 lbs. being lost in transit. The steam-pipe was 2½ inches in diameter and 130 yards long. This pump was worked about 12 days.

Having given the experiences of practical men, and their opinion of the merits of these pumps for use underground, it is only fair to remark that makers do not claim for them an advantageous universality of application. There are circumstances where low first cost, compactness, easy portability, and general handiness are considered of more importance than economy in the use of steam; on the other hand, the conditions may be such as to render the use of a high-duty engine imperative. The many advantages of the underground engine may be obtained at too great a sacrifice of working economy, or, on the other hand, too high a price may be paid for economy of performance in the surface engine.

If the mine is a metalliferous one, remote from the coal centres, and fuel is accordingly dear, and if, moreover, the pumping is heavy, the engineer would probably decide in favour of a surface engine. The practice in metalliferous mines in this country, whatever it may be in the United States, is not in the direction of underground engines.

In collieries, with plenty of refuse coal and 'slack' of little or no commercial value, much of it perhaps worth only a shilling or two per ton, a small initial outlay rather than economy of working, and a plant that occupies little space in the pit, would be considerations that would probably determine the selection of the pumping machinery in favour of an underground engine.

The conclusions that would appear to be fairly deducible from the experience of practical men in the use of surface and underground engines, such as we are now considering, under varying circumstances, and what we know of their design and construction, and their capacity and working results, may be epitomised as below; the factors must be regarded as comparative and not absolute.

Surface Engine:—

1. Large first cost.
2. Machinery heavy and difficult to handle in transit and erection.
3. Occupies considerable space in shaft.
4. Expensive and laborious to erect.

5. Works with great economy of steam.
6. Very durable.
7. Very reliable.
8. Cannot be 'drowned out.'

Underground Engine (of the class now under consideration) :—

1. Small first cost.
2. Light, compact, and handy.
3. Requires little room.
4. Cheap, easy, and quick to erect.
5. Works with little economy of steam.
6. Much wear and tear.
7. Liable to derangement.
8. May be 'drowned out.'

The mine manager or engineer must assess the value to be attached to each of the factors named in view of the special circumstances and exigencies of the case. It is certain that no one class of engines is adapted to the very divergent requirements of mine and colliery drainage; what therefore the engineer has to do, and do most carefully and discriminately, is to consider the whole of the circumstances, and the *pros* and *cons* of the various systems, in order to ascertain where the balance of advantage lies.

Cost.

It will be useful to know the cost of these machines. The prices of different makers for the same size machines vary a little, but the following is a list of the general prices for the sizes given. An extra charge is made for a brass-lined, solid brass, or gun-metal water-cylinder and copper air-vessel. The first table shows the extra cost of a condenser, etc.

Diameter of steam-cylinder	Diameter of water-cylinder	Stroke	Price	Price with condenser, blow-thro'-valve, and exhaust to condenser
in.	in.	in.	£	£
7	6	12	45	61
8	6	12	50	66
9	6	12	55	71
9	8	18	70	94
10	7	12	65	88
10	10	24	95	135
12	8	18	85	112
12	12	24	140	190
14	7	24	110	138
14	12	24	160	215
16	8	24	145	168
16	14	24	195	255
18	9	24	180	225
18	14	24	230	290
20	16	36	335	—
21	12	36	270	330
24	12	36	285	345
26	14	48	400	470

The following tables of prices, etc., are given *in extenso* because they furnish other particulars which are useful. In the second table the delivery of water is calculated upon a piston speed of 100 feet per minute, beyond which speed the pumps referred to should not be worked. For gun-metal linings for barrels 7½ per cent. extra is charged. Packing 5 per cent. extra.

Dia. of steam-cyl.	Dia. of water-cyl.	Length of stroke	Water per hour (approx.)	Price	Price with condenser in suction pipe	Price with air-pump condenser	Dia. of suction and delivery pipes	Dia. of steam pipe	Dia. of exhaust pipe	Height to which water can be raised with 40 lbs. boiler pressure
in.	in.	in.	gallons	£	£	£	in.	in.	in.	ft.
10	5	15	5,496	71	88	99	3½	1½	2½	255
10	7	15	10,776	77	96	107	5	1½	2½	130
10	9	15	17,820	82	104	115	6½	1½	2½	78
12	6	20	7,920	93	115	126	4½	2	2¾	255
12	7	20	10,776	99	128	139	5	2	2¾	186
12	8	20	14,076	104	132	143	6	2	2¾	143
12	10	24	24,000	132	173	187	7½	2	2¾	91
14	7	24	11,760	132	154	170	5½	2½	3	255
14	8	24	15,360	143	165	181	6	2½	3	195
14	9	24	19,440	165	187	203	6½	2½	3	154
14	10	24	24,000	154	198	214	7½	2½	3	125
14	12	24	34,560	181	231	247	9	2½	3	86
16	8	24	15,360	165	187	209	6	3	3½	255
16	9	24	19,440	176	209	231	6½	3	3½	201
16	10	24	24,000	181	231	253	7½	3	3½	162
16	12	24	34,560	209	253	275	9	3	3½	113
16	14	24	47,040	242	275	297	10½	3	3½	83
18	9	28	19,440	209	253	280	7	3½	4	255
18	10	28	24,000	220	264	291	7½	3½	4	206
18	12	28	34,560	242	286	313	9	3½	4	143
18	14	28	47,040	264	308	335	10½	3½	4	105
18	16	28	61,440	297	341	368	12	3½	4	80

Dia. of steam-cyl.	Dia. of water-cyl.	Length of stroke	Water per hour (approx.)	Price	Dia. of suction and delivery pipes	Dia. of steam pipes	Dia. of exhaust pipes	Approx. weight, packed	Nom. H.-P. of boiler required	Height to which water can be raised with 40 lbs. boiler pressure
in.	in.	in.	gallons	£	in.	in.	in.	cwts.		ft.
14	12	36	29,000	210	9	2½	3½	59	14	80
16	10	24	20,000	150	8	3	3¾	50	20	120
16	12	24	29,000	165	9	3	3½	56	20	80
16	12	36	29,000	210	9	3	3¾	59	20	80
16	14	36	39,000	260	10	3	3¾	66	20	80
16	16	36	51,000	290	11	3	3¾	78	20	60
18	12	36	29,000	235	9	3½	4	72	25	136
18	14	36	39,000	270	10	3½	4	83	25	96
18	16	36	51,000	300	11	3½	4	95	25	80
20	12	36	29,000	255	9	3½	4¼	81	30	166
20	14	36	39,000	285	10	3½	4¼	95	30	120
20	16	36	51,000	330	11	3½	4¼	108	30	90
20	20	36	81,600	415	13	3½	4¼	128	30	60

Dia. of steam cyl.	Dia. of water-cyl.	Length of stroke	Water per hour (approx.)	Strokes per min.	Price	Dia. of suction and delivery pipes	Dia. of steam pipes	Height to which water can be raised with 50. lbs. boiler pressure
in.	in.	in.	gallons		£	in.	in.	ft.
10	4	12	2,200	50	65	3	1¼	350
12	4	12	2,200	50	80	3	1½	540
14	6	14	4,100	50	110	4	2½	350
16	6	16	4,500	50	125	4	2½	420
18	8	24	7,500	30	170	6	2½	300
22	8	30	9,400	30	210	6	3½	450
22	10	30	15,250	30	250	8	3½	300
26	10	30	15,250	30	290	8	4	400
22	12	30	21,500	30	300	9	4	200
26	12	30	21,500	30	340	9	4	300

The succeeding tables give the prices, etc., of Duplex ram-pumps. The cost only slightly exceeds that of an ordinary pump capable of performing the same work.

Dia. of steam cyl.	Dia. of water cyl.	L'ngth of stroke	Strokes per minute of *one* plunger	Water per hour *both* plungers at speeds given respectively		Price		Dia. of suct. pipe	Dia. of deliv. pipe	Dia. of steam pipe	Dia. of exhaust pipe	Approx. Wght.
in.	in.	in.		gallons	gallons	£	s.	in.	in.	in.	in.	cwts.
14	5	12	25 to 75	2,400	7,500	182	0	4	3	2½	2½	49
14	6	12	25 to 75	3,480	10,800	197	10	4	3	2½	2½	55
16	6	12	25 to 75	3,480	10,800	234	0	4	3	2½	3	65
16	8	18	20 to 65	7,580	25,200	343	0	6	5	2½	3	100
18	6	18	20 to 65	4,500	14,100	348	10	4	3	3	4	100
18	7	18	20 to 65	6,000	19,200	364	0	5	4	3	4	110
18	8	18	20 to 65	7,500	25,200	374	10	6	5	3	4	115
20	7	18	20 to 65	6,000	19,200	395	10	5	4	4	6	122
20	8	18	20 to 65	7,500	25,200	420	0	6	5	4	6	140
22	8	18	20 to 65	7,500	25,200	447	10	6	5	4	6	140
24	9	18	20 to 65	10,200	32,100	561	10	7	6	5	7	180
25	7	24	15 to 50	6,000	19,200	687	10	5	4	5	7	230
25	9	24	15 to 50	10,200	33,000	730	0	7	6	5	7	250

Dia. of steam-cyl.	Dia. of water-cyl.	Length of stroke	Water per hour	Dia. of suction and delivery pipes	Dia. of steam-pipe	Dia. of exhaust pipe	Price
in.	in.	in.	gallons	in.	in.	in.	£
10	6	8	11,840	4	2	2½	90
12	7	10	16,500	5	2	2½	125
12	8	10	21,600	6	2	2½	155
14	9	10	28,000	7	2½	3	180
14	10	12	38,000	8	2½	3	220
16	12	12	55,120	10	3	4	330

The total cost of installing a pump of this class underground with water and steam-pipes complete is probably not much more than a third that of a surface beam-engine with its masonry, pitwork, etc., for the same work. But if to prevent 'drowning,' or to provide for breakdowns, etc., the plant is duplicated by putting the main engine in a 'station' some

distance up the shaft and fixing another engine near the sump, the cost of the steam-pump plant would be considerably increased and the disparity between the two systems reduced to the same extent.

Duty.

The quality for which the Cornish engine is so renowned, and for which it has, perhaps, for deep and permanent pumping, never been surpassed—the high duty or work performed for a small consumption of fuel—is not possessed by any simple steam-pump, and, indeed, the makers do not profess that their machines are economical in this respect. These pumps, so far from being economical in working, are really very wasteful of steam, and the boiler capacity requisite for keeping them supplied with steam, taking into consideration the relative amounts of work performed, is exceedingly great compared with engines constructed on the most economical principles, such as the Cornish, Bull, Davey's Compound 'Differential,' and other surface pumping engines. The indicator diagram, fig. 13, of a 'Differential' engine shows a very small measure of expansion,

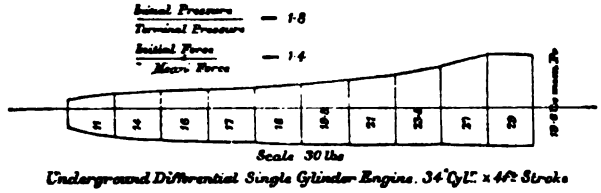

Initial Pressure / Terminal Pressure — 1·8
Initial Press / Mean Press — 1·4
Scale 30 lbs
Underground Differential Single Cylinder Engine. 34"Cyl. x 4ft Stroke

FIG. 57.

the ratios of initial and terminal pressures being only as 1·8 to 1. In a letter to the author the manager of the Tynewydd Colliery, where a 'Special' (steam-cylinder 12 inches, water-cylinder 10 inches, stroke 18 inches) is at work, says: 'We consume about 14 cwt. of bituminous coal (No. 3 Rhondda House Coal) to raise a little over 300 tons of water to the height of 66 feet, but there is a certain quantity of heat lost, as the fires are taken out at night.'[1] This will give a duty of 3,168,000 lbs. raised one foot by the consumption of 1 cwt. of coal; making an allowance for loss of heat as explained, and we have a duty of say 4,000,000, which is about one-sixteenth of that performed in Cornwall by the best Cornish engines; or if we go back to the time when greater attention was paid to the engines and the conditions were more favourable, the difference will be far greater. The well-known Cornish engine erected by the Perran Foundry Co. at the United Mines in the year 1840, gave an average duty during the years 1841 and 1842, according to Mr. Farey, of 95,750,000 lbs., raised 1 foot by the combustion of 1 bushel of coal. Taking the

[1] This pump was supplied with steam by two locomotive boilers placed underground at a distance of 120 yards from the pump, the steam being conveyed in a 2-inch pipe, and exhausted to the atmosphere.—S. M.

bushel to be 94 lbs., this would be equal to a duty of 114,000,000 for 1 cwt. of coal, or nearly 30 times that performed by the steam-pump in question. It may be urged, and with some justice, that the comparison of a small engine placed underground with a large one at surface is not a fair criterion as regards the relative values of the two principles, but as regards actual results the comparison is quite permissible, as it is only under exceptional circumstances that large engines of this kind can be advantageously used.

The use of a condenser, such as Holman's or Floyd's, would effect an appreciable reduction of fuel, and a better performance than that recorded would be obtained, but we do not think that under the most favourable circumstances the duty of pumps of this class would exceed 10,000,000 or 15,000,000 lbs. raised 1 foot by the expenditure of 1 cwt. of coal. It is impossible to make steam-pumps economical without a second cylinder and condenser, but then the lightness and simplicity for which they are noted will be gone.

In a paper[1] read before the Chesterfield and Derbyshire Institute of Engineers, October 2, 1875, by Mr. John B. Simpson, that gentleman assumes that the 'Special' pump will consume at the least from 10 to 12 lbs. of coal per effective horse-power per hour. We are of opinion that engines of this class cannot be worked underground with less than 15 lbs. of coal per effective horse-power per hour, and that under some circumstances it would exceed that quantity. Improvements have been made since Mr. Simpson's paper was written, but having based his remarks on too favourable an estimate of these pumps, his observations will in the main hold good to the present day. We insert them presently with only a very slight curtailment.

In making choice of a steam-pump a long-stroke engine should be preferred to one with a short stroke, as it is more economical, because making fewer strokes for the same piston-speed, it has to fill the clearances between the piston and cover a fewer number of times. For instance, a pump with a 2-feet stroke, running at a piston-speed of 120 feet per minute, makes 30 strokes, and consequently has to fill the ports and clearances 30 times, whereas a 4-feet stroke pump, working at the same speed, would only have to fill them 15 times. 'It is undeniable that the majority of this class of steam-moved pumps have the fault of their use involving a comparatively great expenditure of steam; where the pump is small this may be hardly worthy of notice, but as it becomes of larger diameter and longer stroke, the economy in the consumption of fuel begins to be an important question, and the employment of such pumps has been thus limited to a certain class of cases. . . . This extravagance in the use of steam is a characteristic of direct-acting steam-pumps.'[2]

'The great drawback to this class of pumps, hitherto, has been their

[1] John B. Simpson, M.I.C.E., F.G.S.: *Observations on the Comparison of the Cornish Engine and Holman's 'Special' Pump.* [2] *Engineering*, Sept. 7, 1877.

inordinate consumption of steam. This is a fatal objection in the case of pumps of large size, for very soon the question of economy forces itself upon the notice of the user, and the consumption of fuel becomes a question which he is obliged to take into consideration. As there is no rule without exceptions, perhaps there are certain pumps to which these remarks do not so sweepingly apply, but that a perfect direct-acting pumping engine has been found, few, if any, will be prepared to admit.' [1]

The following are Mr. Simpson's remarks: 'I have read with pleasure Mr. Holman's description of the progress made in pumping machinery, and his statement respecting the Cornish engine. I can fully confirm what he has said of the duty and efficiency of the latter. I must say, however, that I felt considerably disappointed when I came to a description of machinery which Mr. Holman intends to substitute for the Cornish engine, and which furnishes no details of the annual economy of his system of pumping. I expected that a comparison would have been instituted between the old and new systems. . . . Mr. Holman admits that his engine has not hitherto been an economical user of steam.

'Now, as an advocate of the Cornish engine for many years, and the means of its introduction into the North of England collieries, I am not disposed to admit that the engine in question has any claim to be compared with it. It would have added more to the practical utility of this paper had Mr. Holman given us the result of experiments in this respect; but to make up for this omission, I purpose to give an idea of the relative economy of the two engines.

'1st. *The Cornish Engine.*—Assume an engine exerting 500 horse-power of actual duty as mentioned by Mr. Holman. The quantity of coal it would consume annually, assuming the effective duty in water lifted at 4 lbs. per horse-power per hour, or about 50,000,000 duty,[2] would be 7,821 tons, which at 5*s.* gives £1,955

'To this add the interest on cost of engine and pumps, which is estimated by the author at £7,000, say at 10 per cent.[3] . 700

Total per annum . . £2,655

'2nd. *Mr. Holman's Special Engine.*—This engine, working without any expansion or in any economical way as regards steam, will consume at the least 10 to 12 lbs. of coal per horse-power per hour of effective duty. I will assume 10 lbs. This would require 19,552 tons of coal per annum, which at 5*s.* will give . . £4,888

'I do not know the cost of an engine of this description, but probably with the necessary pumps it would be 3,000*l.* at least; then 10 per cent. on this amount gives [3 4] 300

Total per annum . . £5,188

[1] *Mining World*, Oct. 6, 1877.

[2] This is a low estimate of duty for the Cornish engine. Working under ordinary conditions it should do quite 50 per cent. more than this. We do not know if Mr. Simpson based the duty on a low-quality coal, 5*s.* per ton at the pit bank.

[3] For present-day calculations 5 per cent. would be sufficient.

[4] The extra number of boilers required, the greater cost of stoking, slate and other material, and repairs, must be added to this estimate.—S.M.

'This estimate shows a difference in favour of the Cornish engine of 2,533*l.* per annum, when coal is selling at 5*s.* per ton, and of course in times such as we have passed through I need not say how much more the difference would be. I maintain, therefore, as opposed to the author's views, that annual economy is more to be considered than first cost. I have not gone into the question of the labour employed, but I may say that the lesser number of boilers which would be required by the Cornish engine would cause a saving in this respect, and I must contradict the remark made by Mr. Holman, when he says that in his engine the labour is one-twentieth part of that of the Cornish engine.

'One more fact as to the Holman engine. I understand it to be purely an underground engine, and in heavily watered sinkings it will still be requisite to have a surface engine to enable you to reach the point before the "Special" pump can be applied. In this case you have an increased capital, and at a heavy annual outlay, if you substituted the "Special" pump for the Cornish engine.

'There is no doubt that the Cornish engine in first cost is great, and that it has some drawbacks; but I have not yet been able to find any other engine for the draining of mines doing such economical duty, even taking into consideration the interest upon its first cost.

'I will freely admit that the "Special" pump for temporary purposes, and where economy is not an object, has been and is exceedingly useful, and especially where space is an object, and I think that colliery owners should give every encouragement to those engineers who are willing to give their attention and ability to enable the drainage of mines to be accomplished with greater facility and economy. I have no hesitation in saying that there is at the present moment four times as much coal consumed as there ought to be for this purpose. Any engine, however, that does not work expansively or on the compound principle, or is not designed with the object of economy of fuel, will not, in my opinion, be the engine of the future for the permanent drainage of our collieries.

'I cannot agree with the author of this paper that the "Special" pump which he has described is destined to supersede the Cornish engine. The arrangement of the valves and the little attention required, I have no doubt, are objects for admiration, and I fully believe all that Mr. Bigland has stated respecting them; and if Mr. Holman would endeavour to apply the principles of economy to the use of steam in the cylinders, and give us, say, 3 or 4 lbs. effective duty, then perhaps it might be the germ of that engine which he predicts will be the pumping engine of the year 1900.'

Worthington says, 'Engines of this class cannot be depended upon for more than 20,000,000 duty.'[1]

'The ordinary small, direct-acting, single-cylinder pumps, even in their best condition, probably consume about five or six times that amount of fuel (2½ pounds for each I.H.-P. per hour), but when leaking and badly

[1] *History of the Worthington Pumping Engine*, p. 72.

adjusted, as is so often the case, ten times may not be an excessive estimate.'[1] This, reduced to duty of pounds raised one foot high, works out about 16, 11, and 7 millions respectively, and practically confirms the conclusions reached by the author many years ago.

It is very difficult to get any reliable accounts of the duty performance of underground engines, as they are in nearly every instance steamed by boilers which also supply winding and other engines.

If it be considered unfair, without taking into account the great difference in the capital outlay, to compare the duty of an underground engine, the steam for which has come through a long range of pipes, and consequently suffers from the condensation in them, with that of a surface engine which is close to the boiler, and which is enabled to work at a good ratio of expansion, it is not less unfair to institute a comparison between the first cost of the two classes of engines without reference to their duty.

Referring to a D'Auria pump of 12-inch diameter steam-cylinder and 12-inch stroke the 'Mechanical Engineer' says 'a duty of 35,000,000 foot-pounds per 100 lbs. of coal has been obtained, which is from two to three times the duty which might be expected of an ordinary pump of the same size.[2]

1.—SINGLE STEAM-CYLINDER, NON-EXPANSIVE, NON-CONDENSING ENGINES WORKING DOUBLE-ACTING PISTON PUMP.

The 'Special' Piston-Pump.

This pump is the invention of Mr. Adam Scott Cameron, of the United States. The first engine was made in America late in the year 1865. It was first introduced into this country in 1867, the inventor being fortunate in getting such an enterprising firm as Messrs. Tangye Brothers, of Birmingham, to undertake its manufacture. It is one of the most widely known of its class, and since its introduction more than 21,000 examples have been made at the Cornwall Works, Birmingham, ranging from the large compound pump for water works and mine drainage down to the smallest boiler feeder.

This pump is made in a large variety of types and combinations of steam and water-cylinders, and with several kinds of pump-valves, adapting them to various lifts and duties, and under widely divergent circumstances.

The design is good, the valve area liberal compared with the speed, which is 100 feet per minute as a maximum, and the level of the barrel compared with that of the valve-chambers is low. It may be observed that the only moving part open to the air is a small portion of the piston or pump-rod.

The makers claim that the 'Special' steam-pump 'retains its place as the simplest and most compact direct-acting pump on the market.'

[1] Hans C. Behr: *Mine Drainage Pumps, &c.*, p. 123.
[2] The *Mechanical Engineer*, May 7, 1898, p. 525.

The steam-valve gear has been much improved of late years by Messrs. Tangyes. The slide-valve is of the D pattern, placed on the top of the steam-cylinder, and operated by a separate small auxiliary piston which is steam-moved. The inner faces of this piston are subject to the full steam-pressure, but the outer ends of the auxiliary cylinder have only such a quantity of steam as is permitted to leak into them by the special bye-pass valves. These can be adjusted whilst the pump is at work by means of a small spanner, to get the best working speed, etc., for the conditions under which the pump is being used, and they are so simple that any intelligent engine-man can do all that is necessary without difficulty.

The operation is as follows:—When the main piston reaches one end of its stroke it raises a tappet which puts that end of the auxiliary cylinder into connection with the exhaust-pipe, and by so doing the steam-pressure on the other side of the auxiliary piston pushes the valve over and reverses the action of the pump; the same series of movements occur at the other end.

A handle is provided for moving the slide-valve for starting, but is not in motion when the pump is at work, the valve not moving far enough to reach it. As the gear consists of very few parts, and these are all protected, it is claimed that the pump is not liable to injury from blows or from dust, dirt, or other materials falling upon it.

This pump is made in the following types:—

Short Type.—The pumps are strong enough for 'heads'[1] not exceeding 100 feet, and the steam-pressure (in no case to exceed 70 lbs. per square inch) must not be such as to put a greater 'head' than 100 feet on the pump. The steam-cylinder has Floyd's patent adjustment to the valve-chest, and is fitted with starting-handle, cast-iron piston, and rings. The piston-rod is of Muntz metal working through a stuffing-box gland and sleeve of brass. The pump can be made with the suction inlet and the delivery outlet at the front or the back; it has brass valves and cast-iron 'bucket'[2] with leather packings. An air-vessel is not provided, not being considered necessary for such a low lift.

The standard sizes range from 3-inch steam-cylinder, 2½-inch water-cylinder, and 5-inch stroke to 7-inch steam-cylinder, 6-inch water-cylinder, and the same stroke. The approximate dimensions vary from 29 × 13 inches length and width, and 18 inches height overall, to 35 × 19 × 27 inches, and the weight from 1½ to 4¾ cwts. The quantity of water delivered per hour, approximately, for the head named ranges from 1,000 gallons (for the 3 × 2½ × 5 size) to 5,760 gallons (for the 7 × 6 × 5 size).[3] These quantities are based upon the calculated displacement of the pump buckets when running at a piston speed of 80 feet per minute. In selecting a pump a

[1] 'Head' is total vertical height the water is delivered + friction produced by pipes, bends, valves, etc.

[2] See explanatory note, p. 60.

[3] In further references to the size of the steam-cylinder and the water-cylinder and the length of the stroke, we shall, for the sake of brevity, follow the common method of indicating by numerals, with the multiplication sign between, the sizes in the order given.

deduction must be made from the theoretical quantity to allow for loss by leakage, slip, etc.

300 *feet Type.*—In this series the pumps are strong enough for a maximum head of 300 feet, and the steam-cylinders for a maximum steam-pressure of 100 lbs. per square inch. Care must be taken to select a combination that will, without exceeding either of these limits, give the head required with the steam-pressure available.

The standard sizes are graduated from $3 \times 1\frac{1}{2} \times 9$ to $40 \times 20 \times 24$, the approximate delivery of water ranging from 450 to 80,000 gallons per hour. The valves are of brass and of the Double-Way type (see fig. 229), consisting of what is known as a Spindle-Valve, rising on a central rod or spindle against a spring which assists in closing.

In this type the piston-rod is of steel, and works through patent anti-friction stuffing-box glands. The steam-cylinder has Floyd's patent adjustment to the valve-chest, and is fitted with starting-handle, cast-iron piston, and rings. The pump in all sizes up to and including 14 inches, has the suction inlet at the back; the air-vessel, with delivery outlet, can be turned back or front. The pump has brass valves of the kind described, and cast-iron bucket with leather packings. In the 15-inch and larger pumps the valve-box is cast separately and bolted to the pump-barrel, and has multiple brass valves (see fig. 235).

600 *feet Type.*—In this series, which is supplied with or without air-pump condenser, the pumps are strong enough for heads not exceeding 600 feet, and the steam-pressure (in no case to exceed 100 lbs. per square inch) must not be such as to put a greater head on the pump than that stated.

The pump, in all sizes up to and including 10 inches, is of the spherical valve-box type, with suction inlet at the back. In the 11-inch and larger size pumps the valve-box is cast separately and bolted to the pump-barrel, and is supplied with multiple brass valves. The steam-cylinder has Floyd's patent adjustment to the valve-chest; the piston-rod is of Muntz metal.

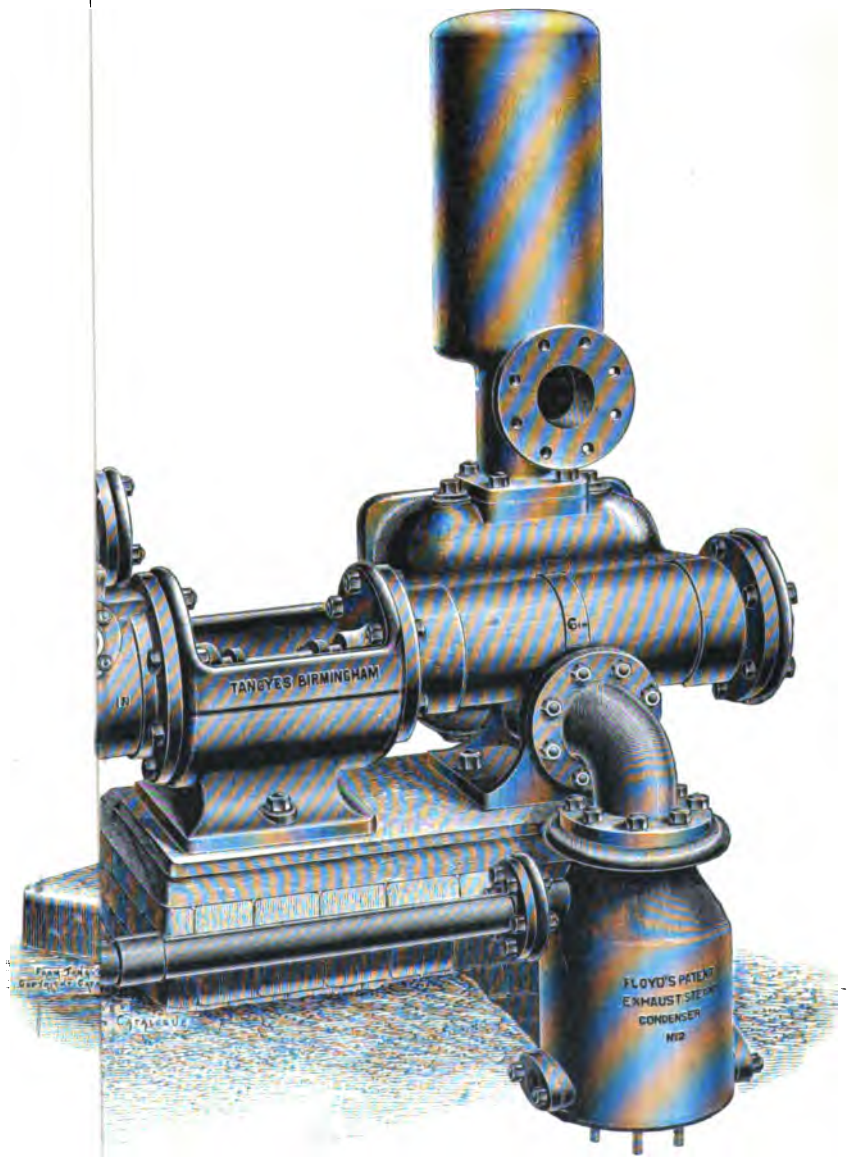
When an air-pump condenser is supplied it is placed at the back of the steam-cylinder, and the whole mounted on a cast-iron base-plate.

The standard sizes of this series range from $7 \times 3 \times 12$ to $40 \times 14 \times 24$, the water raised varying from 1,800 to 39,200 gallons per hour, approximately, according to the head and the combinations of cylinders, and the stroke.

Fig. 58 shows a $14 \times 5 \times 24$ size (600 feet series) and fig. 59, $8 \times 6 \times 12$ size (300 feet series), fitted with Floyd's Patent Exhaust-Steam Condenser. This apparatus is attached to, and practically forms part of, the suction-pipe. It is not suited for use when any other fluid than cold water is being raised.

The pump is interchangeable in all its working parts, all the details being made to exact gauges, and it is only necessary when ordering parts for repairs to state the number stamped on the pump-flange, the date when

PLATE I.



'Special' Piston-Pump (with Floyd's Suction Pipe Condenser).

[*To face p.* 112.

the pump was supplied, and the code word in Messrs. Tangyes catalogue, to get an exact duplicate.

1,000-*feet Type.*—Fig. 60 is an example of the 1,000 feet Outside Valve-box type. The illustration displays an air-pump condenser attached, and shows how readily pumps of this class can be made condensing. The pump is brass-lined, and has brass valves of the multiple type, carried in separate valve-boxes bolted to the pump-body, and bucket with leather packings. The suction inlet is at the front, and the delivery outlet can be turned back or front. The air-vessel is arranged to bolt to the floor at any convenient position near the pump, to which it is connected by piping. When an air-pump condenser is supplied, it is mounted on the base-plate at the back of the steam-cylinder, as shown in fig. 60, and has brass-lined barrel, brass bucket, valve-seats, and guards, india-rubber valves, brass spray pipe, injection valve, vacuum gauge, and connecting pipes to the steam-cylinder.

The standard sizes range from 16 × 4 × 24, with a capacity of 2,560 gallons per hour to 34 × 10 × 24, 16,000 gallons. In the following table the quantities of water are calculated on the displacement of the pump-buckets when running at a piston speed of 80 feet per minute; in selecting a pump a deduction must be made from the theoretical quantity to allow for loss by leakage, slip, etc. The stroke of each pump enumerated is 2 feet.

Dia. of steam-cyl.	Dia. of pump	Water per hour approx.	Dia. of suction and delivery pipes	Dia. of steam-pipe	Dia. of exhaust pipe	Approx. width over all without air vessel	Approx. height over all without air vessel	Approx. length over all without condenser	Approx. length over all with condenser
in.	in.	gall.	in.	in.	in.	in.	in.	in.	in.
16	4	2,560	3	3	3½	42	55	156	225
16	5	4,000	3½	3	3½	42	55	156	225
18	4	2,560	3	3½	4	42	55	156	225
18	5	4,000	3½	3½	4	42	55	156	225
18	6	5,760	4	3½	4	42	55	156	225
21	5	4,000	3½	4	5	43	60	156	225
21	6	5,760	4	4	5	43	60	156	225
21	7	7,840	5	4	5				
24	6	5,760	4	4½	5½				
24	7	7,840	5	4½	5½				
24	8	10,240	6	4½	5½				
26	7	7,840	5	5	6				
26	8	10,240	6	5	6				
26	9	12,960	7	5	6				
28	7	7,840	5	5	6				
28	8	10,240	6	5	6				
28	9	12,960	7	5	6				
30	8	10,240	6	5½	6½				
30	9	12,960	7	5½	6½				
30	10	16,000	8	5½	6½				
32	8	10,240	6	6	7				
32	9	12,960	7	6	7				
32	10	16,000	8	6	7				
34	9	12,960	7	6½	8				
34	10	16,000	8	6½	8				

Makers, Messrs. Tangyes, Limited, Cornwall Works, Birmingham.

The 'Cameron' Piston-Pump.

This engine is the invention of the originator of the 'Special' pump, Adam Scott Cameron, and partakes of its leading characteristics, in that the reverse of the auxiliary piston or plunger is accomplished by the use of two small internal valves, one at each end of the cylinder and struck by the main piston. There is no outside valve mechanism. It is a well-known pump throughout the American and Canadian continent, there being hardly a mining district where it is not at work. Numerous improvements have been introduced from time to time.

Speaking of this pump the 'American Artisan' says:—

'This pump is remarkable for its compactness and simplicity—its parts are few, strong, and very plain. The operation is such that there is not an atom of steam used beyond what is necessary to move it. There is no "dead centre" to the pump—it will start at any point. The pump cylinder is fitted with a piston and four valves of generous proportions. The interior of the cylinder is so arranged as to dispense entirely with "channel ways," "ports," or "passages." By removing one bonnet the whole interior is exposed—turned inside out as it were—and there is not a spot where a single speck can lodge without being detected. The valves used are A. S. Cameron's patent, their construction being such that sand, mud, corn, cinders, &c., can pass through the pump, the valves working perfectly tight under any pressure. The machine works noiselessly. Its compactness, simplicity, strength, lightness, and consequent cheapness must recommend its use in every situation where a pumping engine is required.'

The following references are made by the makers, The A. S. Cameron Steam-Pump Co., East 23rd Street, New York:—

'Patented improvements recently applied have removed every objection that experience has urged against some direct-acting pumps. In the Cameron, the motion of the pistons at the end of the stroke corresponds with that derived from a crank, turning the centres softly, allowing the valves to seat easily, avoiding concussion, and rendering it impossible for the piston to strike the cylinder covers, even when travelling as fast as steam will drive it.'

'The great success of this pump is due to its simplicity and reliability. It has a fewer number of working parts, and is stronger and heavier for capacity than any other pump.

'The steam mechanism consists of four stout pieces only, including the main slide-valve.

'It is the most compact and the least liable to breakage, as none of the working parts are exposed to damage.

'It will always start at any point of the stroke, and run at any speed desired.

'The valve movement of the steam-cylinder working in a direct line with the main piston, without the intervention of arms or levers, enables the pump to be run faster than any other without danger of breaking.

'While under a full pressure of steam the suction pipe can be lifted out of the water without danger of the piston striking the ends. The advantage is apparent, for a pump may be running along on a regular duty under a full pressure of steam, and the supply of water be suddenly cut off.

'Every pump can be taken apart without disconnecting the pipes.

'The parts of the water-cylinder are so arranged that they cannot possibly become deranged; there are no valve bolts nor screws to become loose; the whole interior of the valve chest is exposed by simply removing one bonnet, and the water valves can be taken out and replaced almost instantly.'

Fig. 61 is a section of the steam-cylinder; A is the steam-cylinder; C, the piston; D, the piston-rod; L, the steam-chest; F, the chest piston or

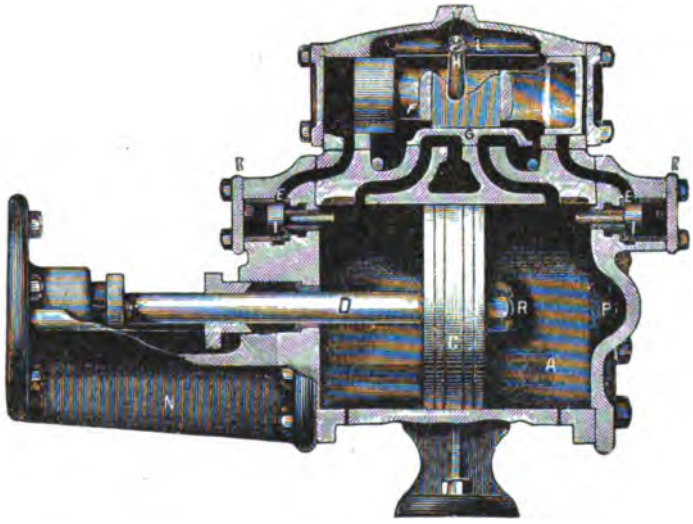


FIG. 61.—The 'A. S. Cameron' Piston-Pump. Longitudinal section of Steam-Cylinder, &c.

plunger, the right-hand end of which is shown in section; G, the slide-valve; H, a starting-bar connected with a handle on the outside; I I are reversing-valves; K K are the bonnets over reversing-valve chambers; and E E are exhaust ports leading from the ends of steam-chest direct to the main exhaust and closed by the reversing-valves I I; N is the body piece connecting the steam and water-cylinders.

The operation is as follows:—Steam is admitted to the steam-chest, and through small holes in the ends of the plunger F, fills the spaces at the ends and the ports E E as far as the reversing-valves I I. With the plunger F and slide-valve G in position to the right (as shown in cut), steam would be admitted to the right-hand end of the steam-cylinder A, and the piston C would be moved to the left. When it reaches the revers-

ing-valve I, it opens it and exhausts the space at the left-hand end of the plunger F, through the passage E; the expansion of steam at the right-hand end changes the position of the plunger F, and with it the slide-valve G, and the motion of the piston C is instantly reversed. The same operation repeated makes the motion continuous. In its movement the plunger F acts as a slide-valve to shut off the ports E E, and is cushioned on the confined steam between the ports and steam-chest cover. The reversing-valves I I are closed immediately the piston C leaves them, by a pressure of steam on their outer ends, conveyed direct from the steam-chest.

The standard sizes of the regular pattern, omitting the smaller pumps, are as follows :—

Dia. of steam cyl.	Dia. of pump	Length of stroke	Ordy no. of strokes per minute	Water per stroke	Water per hour at ordinary speed	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Floor space
in.	in.	in.		gall.	gall.	in.	in.	in.	in.	in.
10	5	13	90	1·10	6,000	4	3	1¼	2	64 × 21
10	6	13	90	1·58	9,000	4	3½	1¼	2	64 × 21
12	7	13	90	2·16	12,000	5	4	1½	2½	66 × 24
14	8	13	90	2·83	15,660	5	5	2	3	73 × 26
14	9	18	67	4·96	19,800	6	5	2	3	81 × 30
16	10½	18	67	6·75	27,000	8	6	2½	4	90 × 37
18	12	20	60	9·80	35,220	10	8	3	4	103 × 41

The long-stroke pattern, which is particularly adapted to situations where continuous work is required, is made in the sizes given below. The stroke of the piston being twice the length of the regular pump, the working parts are brought into action only one-half the number of times for the same amount of work, consequently there is but half the wear on all but the pistons and rod. The valve-chests are placed at each end of the pump-cylinder, permitting of large and short water passages. These pumps are built strong and substantial, to stand the continuous heavy work for which they are intended. For section of pump-valves, see fig. 239.

Dia. of steam cyl.	Dia. of pump	Length of stroke	Water per stroke	Water per hour at ordinary speed	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Length over all	Width over all	Height over all
in.	in.	in.	gall.	gall.	in.	in.	in.	in.	ft. in.	ft. in.	ft. in.
10	5	25	2·12	7,500	4	3½	1¼	2	7 3	1 10	3 9
10	6	25	3·	10,500	5	3½	1¼	2	7 3	1 10	3 9
12	7	25	4·17	13,500	6	4	1½	2½	7 6	2	4 9
14	9	33	9·07	21,000	8	6	2	3	9 10	2 6	5 10
16	10½	33	12·37	27,000	10	8	2½	4	10 2	3	6 2
18	12	38	18·60	36,000	12	10	3	4	11 10	3 6	7 8

THE 'KNOWLES' PISTON-PUMP.

Of the various types of the 'Knowles' pump, the invention of Lucius J. Knowles, of Warren, Massachusetts, a prodigious number are in use

principally in the United States and Canada. Of the 107,000 pumps that have been made more than 20,000 are said to be at work in mines. They do not appear to have been introduced into British mines, at least not to a great extent, but with the 'Blake' and the 'Cameron' pumps they occupy a very prominent position and cover a very wide field in foreign mines.

The piston mining-pumps are made in two patterns—the 'Flat-Cap'

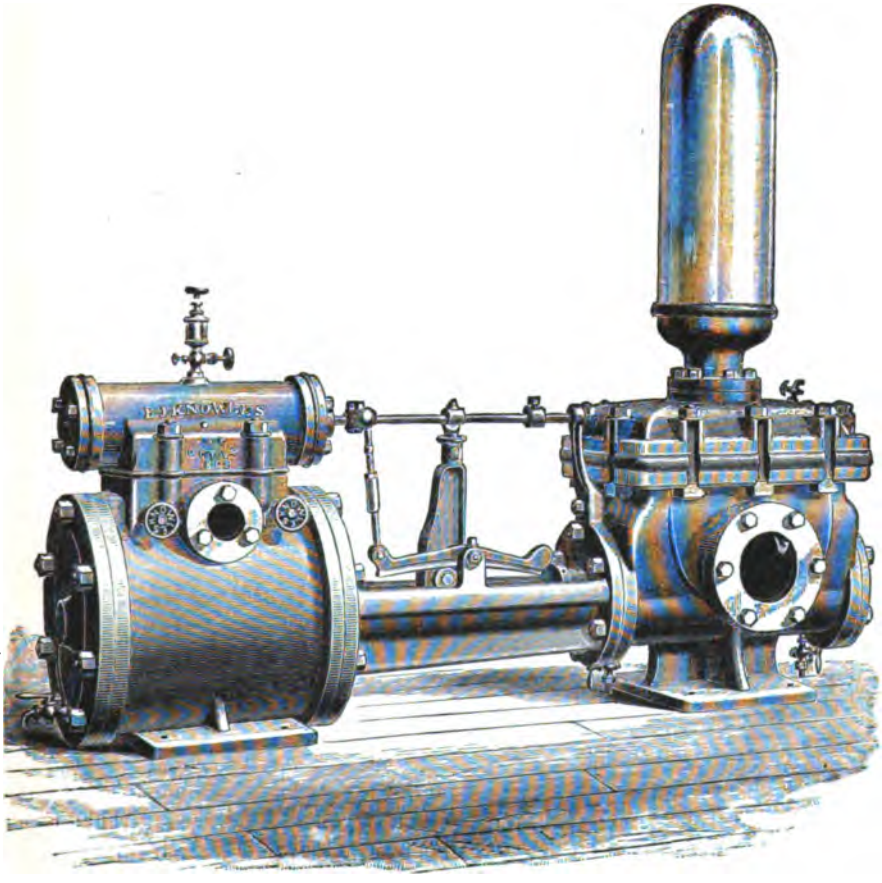


FIG. 62.—The 'Knowles' Piston-Pump.

and the 'Double-Cap,' with removable cylinder. Fig. 62 represents a regular flat-cap pattern. The design of the pump shown is one of compactness and durability. The water-piston is made of gun-metal composition, packed with fibrous packing, and is set out by adjustable screws and nuts. The lining, piston-rod, valve-seats, valve-bolts, and other working parts coming in contact with the mine water, are also made of gun-metal composition. The water-cylinder has large valve area, with easy access

to the valves without disturbing any other parts; the valves and valve-bolts, like other parts of the pump, can readily be removed and duplicated at small expense, in case of wear or accidental breakage, as all parts are made to exact gauges. The valves are of best vulcanised rubber or other material, are easily accessible, and reached by convenient hand-hole plates, and readily removed and duplicated, like all the other working and wearing parts.

This pump is well adapted for ordinary lifts, where the water is usually free from grit and dirt, and not too strongly impregnated with sulphurous or other acids.

Where the water is very gritty the water-cylinder is provided with a removable cylinder or pump barrel—a substantial casting of gun-metal composition—which can be easily taken out and replaced by a new one whenever required. The pumping need not be interrupted more than from ten to fifteen minutes to make the exchange. The removable cylinder can be partially turned in the pump, so that as the bottom part (where the greatest wear naturally takes place) is cut or worn, a new surface can be brought into position.

The makers claim that the 'Knowles' pump is anything but an intricate or complicated machine; on the contrary, it is very simple in its mechanism and readily understood; it requires but little trouble in its care or management, and very small expense is necessary to keep it in good repair.

The steam-valve mechanism consists of an auxiliary valve or 'chest piston' as it is called, which works in the steam-chest and mechanically moves the main valve, which is a plain slide of the B form, working on a flat seat. Motion is given to the auxiliary piston by a tappet arm on the main piston-rod.

The chest piston is slightly rotated by the valve motion; this rotative movement places the small steam ports (which are located in the under side of the said chest piston) in proper contact with corresponding ports cut in the steam-chest. The steam entering through the port at one end and filling the space between the chest piston and the head, drives the said piston to the end of its stroke, and, as before mentioned, carries the main slide-valve with it (see fig. 63). When the chest piston has travelled a certain distance, a port on the opposite end is uncovered and steam there enters, stopping its further travel by giving it the necessary cushion. In other words, when the rotative motion is given to the auxiliary or valve-driving piston by the mechanism outside, it opens the port to steam admission on one end, and at the same time opens the port on the other end to the exhaust. Thus instant and *positive* motion is secured with but few working parts. There is no point in the stroke at which either the chest piston or the main piston is not open to direct steam pressure. Hence there is absolute freedom from what is termed a 'dead centre.' Figs. 64 and 65 are the steam-valve and chest-piston respectively.

The *modus operandi* is as follows: The piston-rod, with its tappet arm, moves backward and forward from the impulse given by the steam-piston. At the lower part of this tappet arm is attached a stud or bolt on which there is a friction roller which, with its bolt and nut, can be lowered or raised when it is desired to adjust the pump for a longer or shorter stroke. This roller, coming in contact with the 'rocker bar' at the end of each stroke, operates the latter. The motion given the 'rocker bar' is transmitted to the valve-rod by means of the connection between, causing the valve-rod to partially rotate. This action, as mentioned above, operates the chest-piston, which carries with it the main slide-valve. The

FIG. 65.

FIG. 64.

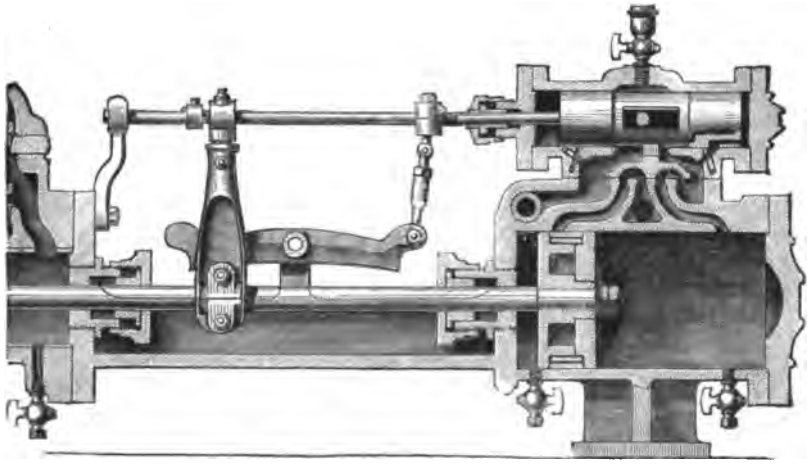


FIG. 63.—The 'Knowles' Piston-Pump; longitudinal section of Steam-Cylinder, &c.

said valve giving steam to the main piston, the operation of the pump is complete and continuous. The upper end of the tappet arm does not come in contact with the tappets on the valve-rod, except the steam pressure from any cause should fail to move the chest-piston, in which case the tappet arm moves it mechanically. This makes the pump absolutely positive.

This pump is made in the same standard sizes and combinations as the 'Blake' pump (see page 125).

The makers of this pump are The Blake & Knowles Steam-Pump Works, Ltd., of New York and London, who also manufacture the 'Blake' pump.

The 'Davidson' Piston-Pump.

Fig. 66 is an elevation and fig. 67 a sectional elevation of this pump, yet another variety of the tappet class, the invention of Mr. M. T. Davidson, of Brooklyn, New York. It will be observed that the steam-valve is actuated by a rotary tappet or cam by a positive mechanical

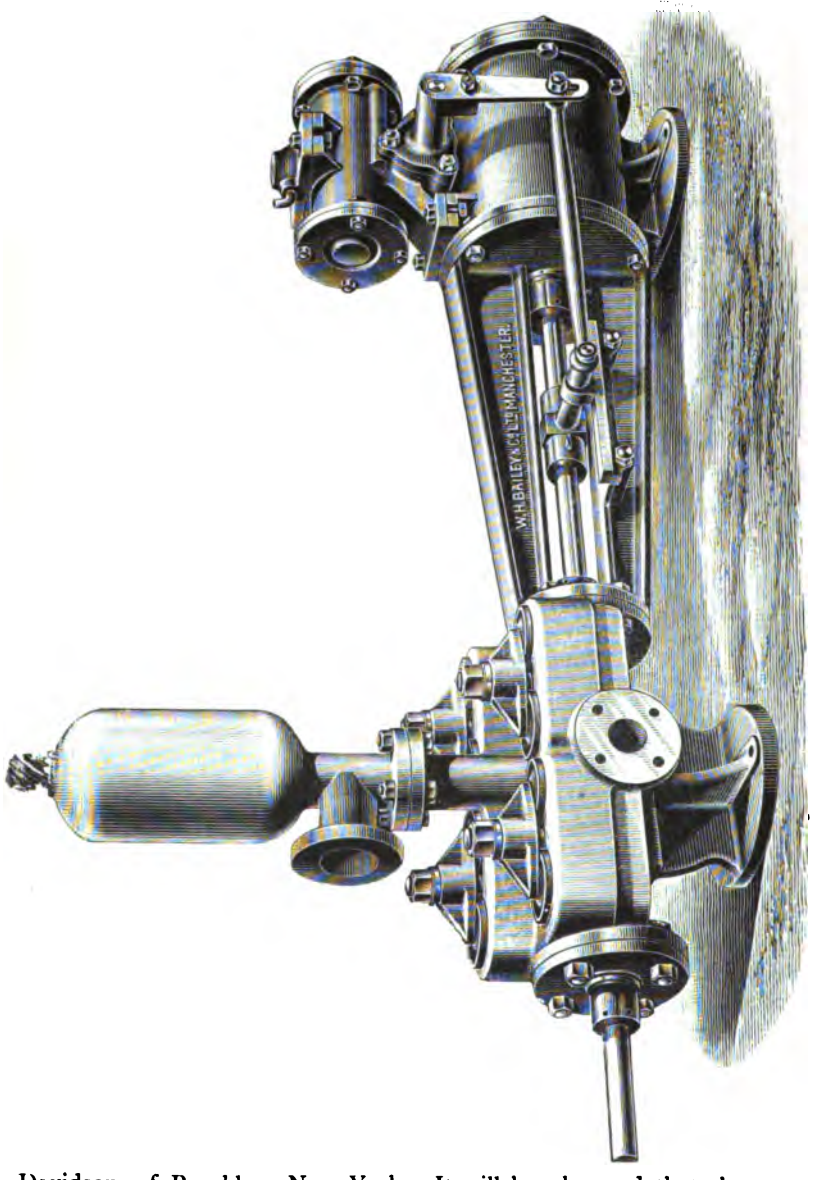


Fig. 66.—The 'Davidson' Piston-Pump.

connection with the main piston-rod. The valve is consequently as much under the control of the piston-rod as is the valve of an ordinary steam engine worked by an eccentric. The valve is also actuated by steam.

The pistons are connected in the manner shown, sufficient space being allowed between them for the valve and steam ports, and they are also connected to the slide-valve, all working in the same plane and being of the same diameter. The valve is oscillated by a cam, connected with the valve by a steel pin passing through the valve into the exhaust port, in which the cam is placed. The moving of the valve does not depend entirely upon the steam admitted to the end of the piston, for should that not be

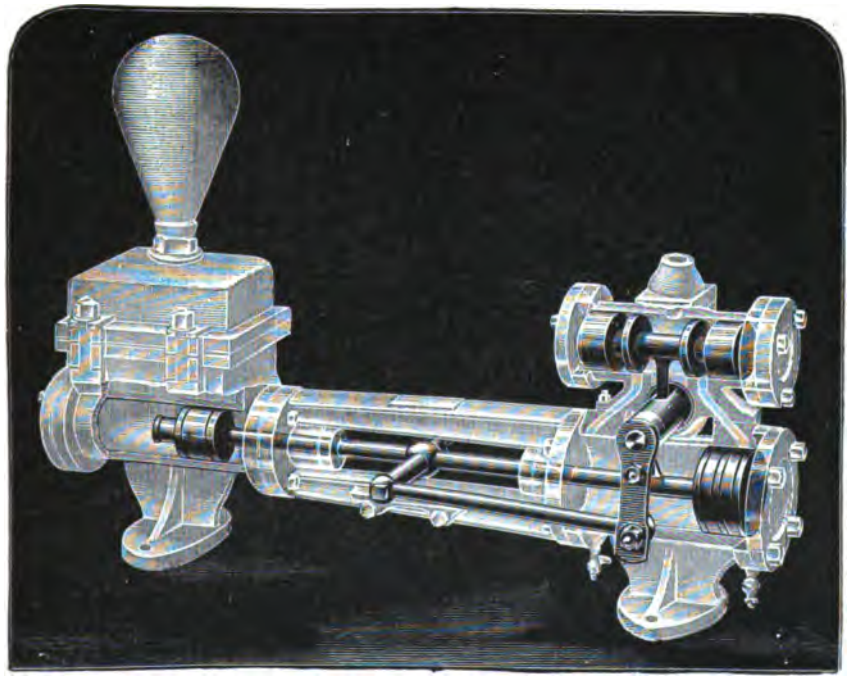


FIG. 67.—The 'Davidson' Piston-Pump; longitudinal section of Steam and Water-Cylinders, etc.

quick enough to operate the valve, with the pump under a high rate of speed, the cam is so constructed that it will carry the valve mechanically, and thus prevent the slightest concussion.

Fig. 68 represents the 'Davidson' Independent Air-Pump and Jet Condenser, by the use of which it is claimed the power of non-condensing engines is increased from 20 to 25 per cent., or when increase of power is not desired it effects a proportionate saving in fuel. It can be set up by any mechanic, and being independent of the engine it can be started to free the cylinder of water and form a vacuum before starting the engine. It will lift its injection water. It is claimed that it requires less power to drive

it than an air-pump worked by the engine, and can be run at a moderate speed, a great advantage over an air-pump which is worked by the piston-rod of a high-speed engine.

The condenser is provided with an automatic arrangement for preventing the water from flooding the cylinder of the steam-engine, and any rise of pressure in the condenser through stoppage of the injection water.

The following table of sizes, capacities, and prices will be of service. A Vacuum Gauge and Injection Valve are included in the prices given. The

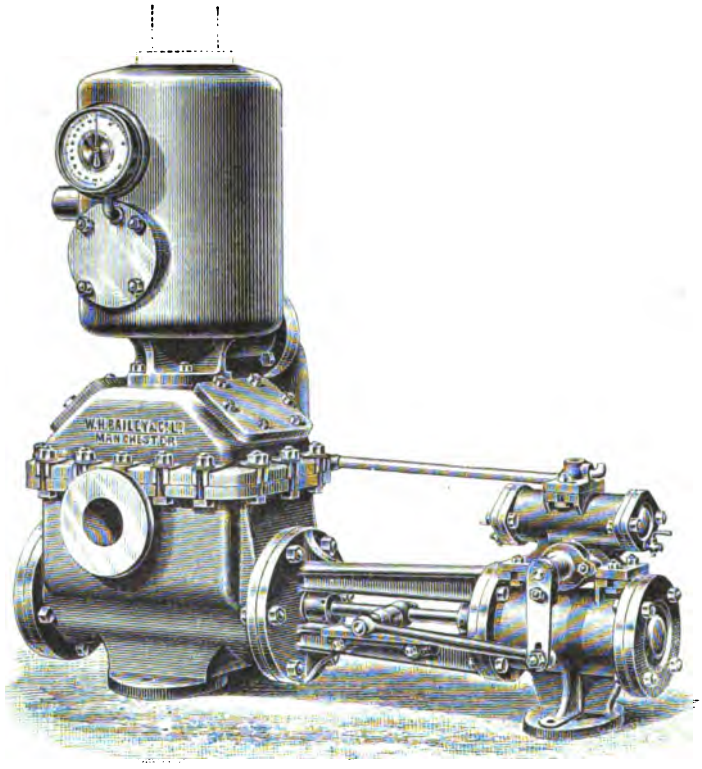


FIG. 68.—The 'Davidson' Patent Air-Pump and Jet Condenser.

Injection Pipe is of copper, and the valves, seating, glands, and cylinder-lining are of gun-metal.

Dia. of steam-cylinder	Dia. of pump-cylinder	Length of stroke	Suitable for engines of	Dia. of steam pipe	Dia. of exhaust pipe	Dia. of exhaust opening	Price
in.	in.	in.	H.P.	in.	in.	in.	£
4½	5¼	12	1 to 50	¾	1	5	50
5¼	7	12	1 ,, 75	¾	1	5	70
7	9	12	75 ,, 100	1	1¼	6	110
9	10½	12	100 ,, 125	1	1¼	6	160
10	12	12	125 ,, 175	1¼	2	6	220

The makers are Messrs. W. H. Bailey & Co., Ltd., Salford, Manchester.

The 'Northey' Piston-Pump.

Fig. 69 is a sectional elevation of this pump, which is made by the Northey Manufacturing Company, Ltd., Toronto, Canada. It belongs, as will be observed, to the tappet class of pumps. The main steam-valve is in two parts, the upper, operated by a starting-piston, admits steam to one end of the main piston and exhausts from the other. The main piston near the end of the stroke sets in motion a rod through the medium of levers anchored to the piston-rod, and this rod carries the lower slide-valve with it, and steam is admitted to one end of the said starting-piston, shifting it over, and thereby bringing it again into position for steaming the main piston.

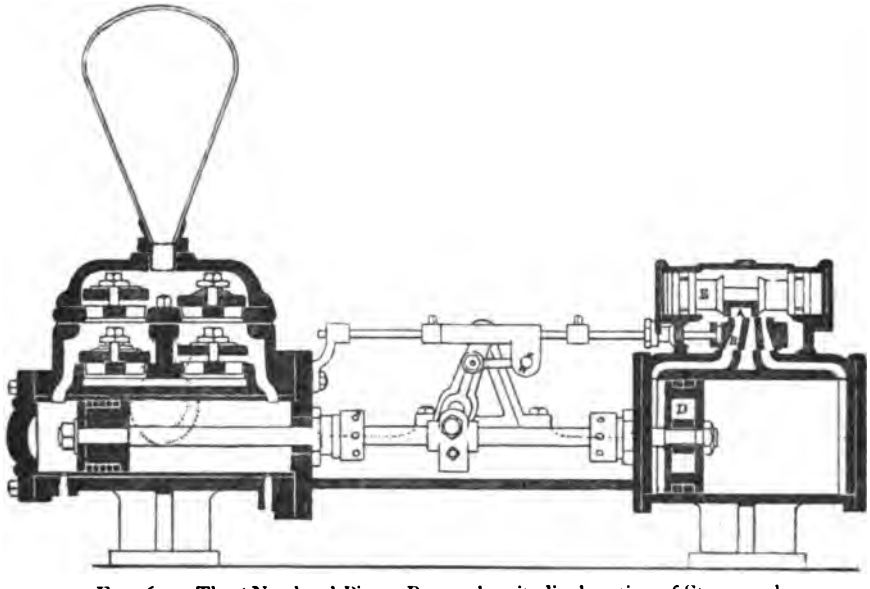


FIG. 69.—The 'Northey' Piston-Pump; longitudinal section of Steam and Water-Cylinder, etc.

With the aid of the section, fig. 69, we will endeavour to describe more minutely the operation of the engine. The main valve, as already stated, is in two parts, marked A and B, the upper part (A) of which slides on the face of the lower part (B), which in its turn slides on its seat on the face of the main cylinder. Motion is given to the valve A by the small piston E, with which it engages, and to the valve B by the rod C, which in its turn is actuated by the valve gear connected to the main piston-rod. When the main piston has nearly reached the end of its stroke, and the steam-valves and parts are in the position shown, the valve gear moves the rod C from right to left, and causes the valve B to travel with it. On the sides of the valve B are small lugs which are cast with it, and form flat valves covering steam and exhaust ports connected with the small upper cylinder. As the

valve B travels over, steam is given to the left-hand end of the small piston E, causing it to move to the right, carrying the valve A with it; and the valves now being in the position opposite to that shown in the engraving, steam is admitted to the left-hand end of the main cylinder and exhausted from the right. Operations similar to those above described will then follow, and will continue so long as steam is admitted. This simple

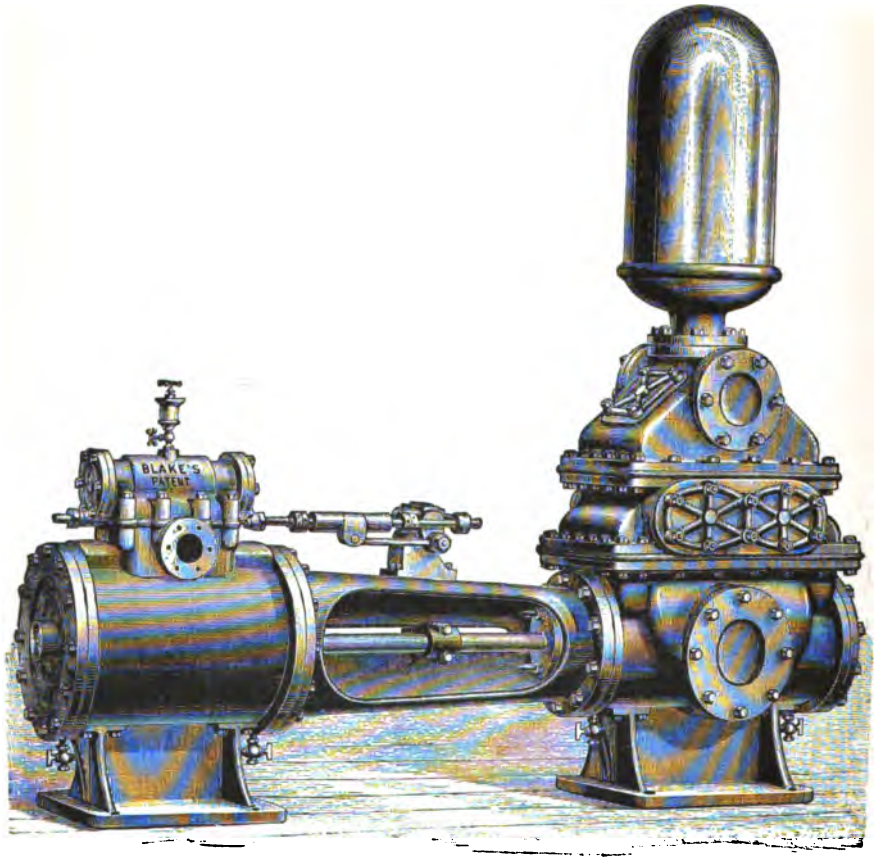


FIG. 70.—The 'Blake' Piston-Pump.

arrangement makes the pump positive in its action under all circumstances, and insures instant starting when steam is admitted.

A very important feature of this valve gear is that the main piston D cannot strike the cylinder-head, as the valve B is always in position to admit steam in front of it just before it reaches the end of its stroke.

This engine can be supplied with a special pump-end, with a removable cylinder or pump-barrel for dealing with gritty water. To obviate unequal wear the removable cylinder is arranged to be partially turned in the pump,

thus presenting a new surface and equally distributing the wear over every portion of the pump-barrel.

The 'Blake' Piston-Pump.

This pump, the invention of Mr. G. F. Blake, of Boston, United States, is another example of the lever and tappet arrangement for operating the

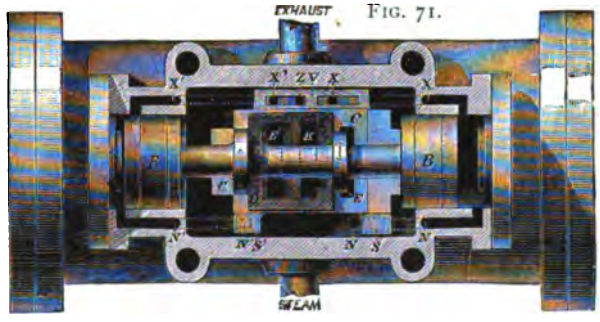


FIG. 71.

FIG. 73.

FIG. 74.

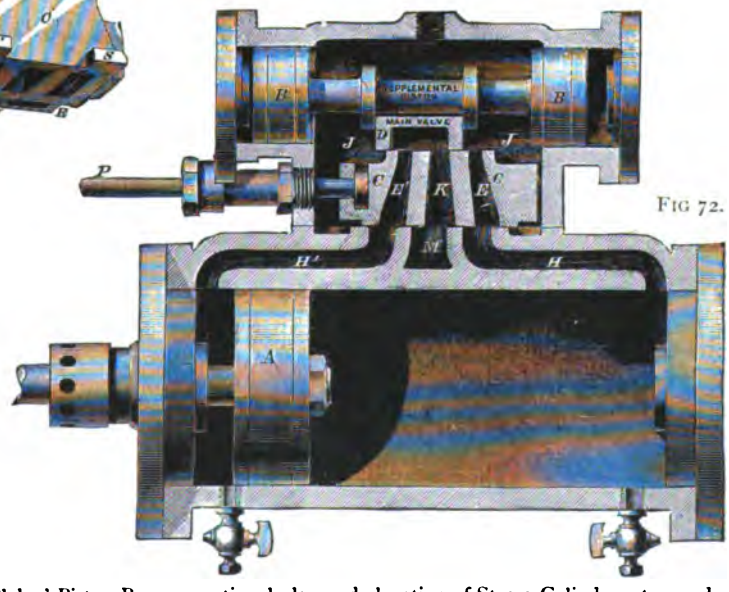


FIG 72.

The 'Blake' Piston-Pump; sectional plan and elevation of Steam-Cylinder, etc., and views of Main Valve.

steam-valve. The main piston, through the intermediary of the piston-rod and a lever, gives an impulse to a tappet-rod which is attached to an auxiliary valve, and thereby admits steam to one end of a valve-driving piston which carries the main valve (a D-slide, working on the upper face

of the auxiliary valve) and exhaust takes place on the other. Steam is thus admitted to one end of the main cylinder, whilst the other is opened to the exhaust ports.

Fig. 70 is an elevation, figs. 71 and 72 plan and elevation in section, showing steam-cylinder, valves, etc.; figs. 73 and 74 are the main steam-valve, which is made in two parts.

Referring to the sectional elevation, fig. 72, it will be observed that the main steam-cylinder is surmounted by a small secondary cylinder, which contains an auxiliary piston—a double-headed spring-ring piston—for actuating the main D-slide-valve, which fits between two collars, by which it is mechanically moved. The main valve works on the top of a three-ported auxiliary slide-valve contained in a chamber in the bottom of the auxiliary cylinder. It will be seen that the ports of the auxiliary valve correspond with those of the main cylinder. Both the main and auxiliary valves are plain flat slides, the main valve being a common D-valve, and the auxiliary a valve of the form shown. The latter, being attached to a rod which receives an impulse from the main steam-piston, is moved with the same absolute certainty as is the slide-valve of an ordinary engine driven by an eccentric.

The 'Blake' pump is positive in its action; the operation at the slowest speed, under any pressure, is perfectly continuous, and the pump is never liable to stop as the main valve passes its centre. An ingenious and simple arrangement is used in the 'Blake' pump to overcome the 'dead centre,' as will be seen from the illustrations and the following description of the operation.

The main or pump-driving piston, A, could not be made to work slowly were the main valve to derive its movement solely from this piston; for when this valve had reached the centre of its stroke, in which position the ports leading to the main cylinder would be closed, no steam could enter the cylinder to act on the said piston, consequently the latter would come to rest, since its momentum would be insufficient to keep it in motion, and the main valve would remain in its central position or 'dead centre.' To shift this valve from its central position and admit steam in front of the main piston (whereby the motion of the piston is reversed and its action continued), some agent independent of the main piston must be used. In the 'Blake' pump this independent agent is the supplemental or valve-driving piston B.

The main valve, which controls the admission of steam to, and the escape of steam from, the main cylinder, is divided into two parts, one of which, C, slides upon a seat on the main cylinder, and at the same time affords a seat for the other part, D, which slides upon the upper face of C. As shown in the engravings, D is at the left-hand end of its stroke, and C at the opposite or right-hand end of its stroke. Steam from the steam-chest, J, is therefore entering the right-hand end of the main cylinder through the ports E and H, and the exhaust is escaping through the ports H′, E′, K, and

M, which causes the main piston, A, to move from right to left. When this piston has nearly reached the left-hand end of its cylinder, the valve motion (not shown) moves the valve-rod P, and thus causes C, together with its supplemental valves R and S S′ (which form, with C, one casting), to be moved from right to left. This movement causes steam to be admitted to the left-hand end of the supplemental cylinder, whereby its piston, B, will be forced toward the right, carrying D with it to the opposite or right-hand end of its stroke; for the movement of S closes N (the steam port leading to the right-hand end), and the movement of S′ opens N′ (the steam port leading to the opposite or left-hand end), at the same time the movement of V opens the right-hand end of this cylinder to the exhaust, through the exhaust ports X and Z. The parts C and D now have positions opposite to those shown in the illustrations, and steam is therefore entering the main cylinder through the ports E′ and H′, and escaping through the ports H, E, K, and M, which will cause the main piston, A, to move in the opposite direction, or from left to right, and operations similar to those already described will follow, when the piston approaches the right-hand end of its cylinder. By this simple arrangement the pump is rendered positive in its action, that is, it will instantly start and continue working the moment steam is admitted to the steam-chest.

The main piston A cannot strike the heads of its cylinder; for the main valve has a lead, or, in other words, steam is always admitted in front of the said piston just before it reaches either end of its cylinder, even should the supplemental piston, B, be tardy in its action and remain with D at that end toward which the piston A is moving, for C would be moved far enough to open the steam port leading to the main cylinder, since the possible travel of C is greater than that of D.

The supplemental piston B cannot strike the heads of its cylinder, for in its alternate passage beyond the exhaust ports X and X′, it cushions on the vapour entrapped in the ends of this cylinder.

This pump is provided with a removable cylinder, similar to those already described, for handling gritty water. It sometimes occurs that the use of a plunger-pump, which is best adapted for water carrying solid matter, or is charged with acids, or both, is prohibited on account of limited room or other adverse circumstances; a piston-pump therefore becomes a necessity, and the removable cylinder is of great value in promoting the durability of the pump and economising time and money.

The tables on the next page give the principal sizes (omitting the smaller ones) of the three standard types of the 'Blake' Piston Pattern, Removable-Cylinder Pattern, and Double-Plunger Pattern.

Dia. steam cylinder	Dia. pump	Length of stroke	Water per stroke	Water per hour in gallons at given strokes per minute	Dia. suction pipe	Dia. delivery pipe	Dia. steam pipe	Dia. exhaust pipe
in.	in.	in.	gall.		in.	in.	in.	in.
20	8	18	3·92	67 Strokes, 15,758 gals.	6	4	3	4
20	8	24	5·22	50 ,, 15,660 ,,	8	6	3	4
20	9	18	4·96	67 ,, 19,939 ,,	8	6	3	4
20	9	24	6·60	50 ,, 19,800 ,,	8	6	3	4
20	9	36	9·92	34 ,, 20,236 ,,	8	6	3	4
20	10	18	6·12	60 ,, 22,032 ,,	8	6	3	4
20	10	24	8·16	45 ,, 22,032 ,,	10	8	3	4
20	10	36	12·24	30 ,, 22,032 ,,	10	8	3	4
20	12	24	11·75	45 ,, 31,725 ,,	10	8	3	4
20	12	36	17·63	30 ,, 31,734 ,,	12	10	3	4
20	14	24	16·00	45 ,, 43,200 ,,	12	10	3	4
20	14	36	24·00	30 ,, 43,200 ,,	12	10	3	4
24	9	24	6·60	50 ,, 19,800 ,,	8	6	4	4½
24	9	36	9·92	34 ,, 20,236 ,,	8	6	4	4½
24	10	24	8·16	45 ,, 22,032 ,,	10	8	4	4½
24	10	36	12·24	30 ,, 22,032 ,,	10	8	4	4½
24	12	24	11·75	45 ,, 31,725 ,,	10	8	4	4½
24	12	36	17·63	30 ,, 31,734 ,,	12	10	4	4½
24	14	24	16·00	45 ,, 43,200 ,,	12	10	4	4½
24	14	36	24·00	30 ,, 43,200 ,,	12	10	4	4½
24	16	24	20·88	45 ,, 56,376 ,,	14	12	4	4½
24	16	36	31·32	30 ,, 56,376 ,,	14	12	4	4½
28	10	24	8·16	45 ,, 22,032 ,,	10	8	4½	5
28	10	36	12·24	30 ,, 22,032 ,,	10	8	4½	5
28	12	24	11·75	45 ,, 31,725 ,,	10	8	4½	5
28	12	36	17·63	30 ,, 31,734 ,,	12	10	4½	5
28	14	24	16·00	45 ,, 43,200 ,,	12	10	4½	5
28	14	36	24·00	30 ,, 43,200 ,,	12	10	4½	5
28	16	24	20·88	45 ,, 56,376 ,,	14	12	4½	5
28	16	36	31·32	30 ,, 56,376 ,,	14	12	4½	5
30	10	24	8·16	45 ,, 22,032 ,,	10	8	5	6
30	10	36	12·24	30 ,, 22,032 ,,	10	8	5	6
30	12	24	11·75	45 ,, 31,725 ,,	10	8	5	6
30	12	36	17·63	30 ,, 31,734 ,,	12	10	5	6
30	14	24	16·00	45 ,, 43,200 ,,	12	10	5	6
30	14	36	24·00	30 ,, 43,200 ,,	12	10	5	6
30	16	24	20·88	45 ,, 56,376 ,,	14	12	5	6
30	16	36	31·32	30 ,, 56,376 ,,	14	12	5	6
30	18	24	26·44	45 ,, 71,388 ,,	16	14	5	6
30	18	36	39·66	30 ,, 71,388 ,,	16	14	5	6

The 'Selden' Piston-Pump.

This piston-pump was introduced about twenty-six years ago by Messrs. J. H. Wilson & Co., of Liverpool. A longitudinal section and a back elevation are shown in figs. 75 and 76. It will be seen that this pump belongs to the tappet class. The bottom of the valve-chamber contains a main D slide-valve and two starting-slide-valves, D D, one on each side of the main valve, and all working upon the same face. Each starting-valve is attached to a spindle working through a stuffing-box at each end of the chamber. Each spindle is connected to a lever, C, which is actuated by a tappet, B, in the end of the main cylinder. The

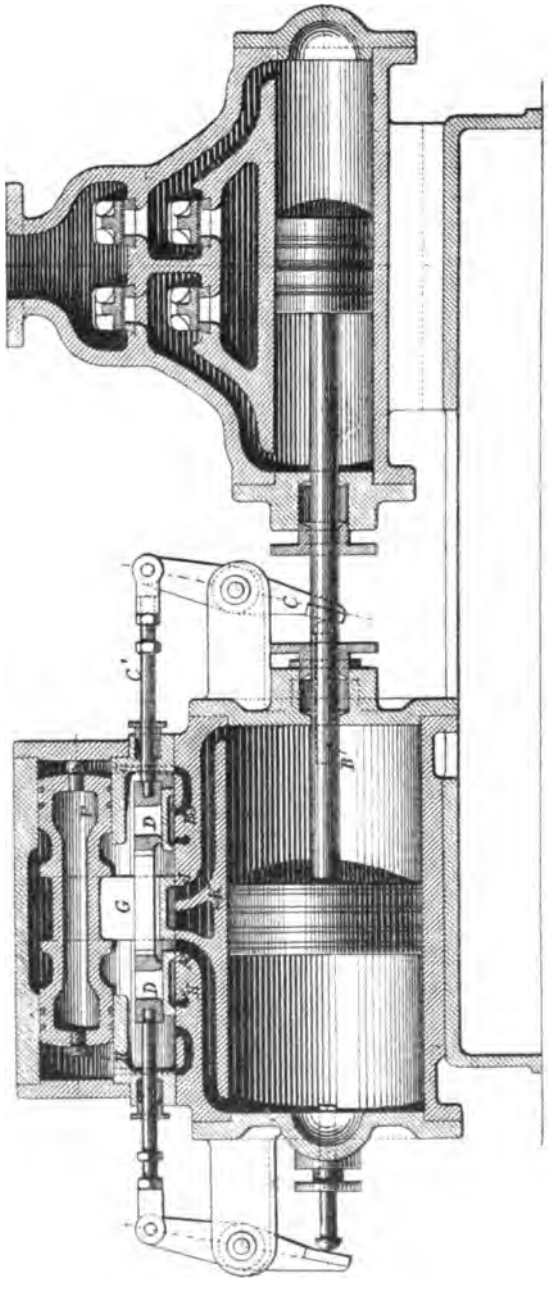


FIG. 75.—The 'Selden' Piston-Pump; longitudinal section of Steam and Water-Cylinders, etc.

top part of the valve-chamber contains an annular auxiliary or shooting-valve, F, with a piston-head at each end, the main slide-valve being attached midway between the piston-heads. The main cylinder contains the usual pair of steam ports, and the exhaust branch, covered by the main slide-valve in the centre of its face. At each end of the face is a small steam port, E (communicating with the ends of the shooting-valve), and an exhaust branch, H, discharging into the main exhaust; these are covered by the starting slide-valves. The tappets before referred to receive their motion from the main piston, which is of the ordinary type. We will suppose the latter to be travelling towards the right-hand end of the cylinder. Near the end of its stroke it strikes a tappet, B, in the end of the cylinder, which gives motion through a double-ended lever, C (anchored to a fulcrum on the cylinder-end), to the starting slide-valves D D, causing them to make a stroke to the left, thereby uncovering the auxiliary steam port, E, at the right-hand end of the cylinder, and admitting steam behind the right-hand end of the shooting-valve, F (the left-hand end being simultaneously open to the exhaust, H H'), driving it and the main slide-valve, G, to the left. The steam is thus diverted from the left-hand end of the main cylinder to the right-hand end, through the port, I; the used steam at the opposite end at the same time escaping to the exhaust through the ports, A K.

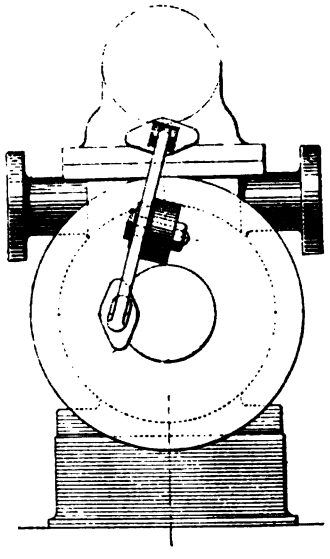


FIG. 76.—End Elevation of Steam-Cylinder.

If it happen that the auxiliary piston is retarded in its action, the starting-valve compensates for the irregularity by tapping the main valve and giving the required cushion to the piston. The advantage gained by this arrangement of valve gear is that the main valve on reversing immediately opens to the full extent for the return, thereby giving the piston full pressure during the whole of the stroke.

THE 'CORNISH' STEAM-PUMP.

It will be observed on reference to fig. 77, which represents an 8 × 5 × 12 pump of the 300-feet pattern, that the steam-chest is placed alongside the main cylinder instead of on it as in the preceding and general examples. The illustration shows two air-vessels, one on the suction-pipe, the other on the delivery-main. In fig. 78 (a 9 × 5 × 12 pump of the same

series) the pump is fitted with Evans's Improved 'Cornish' Condenser attached to the suction-pipe, similarly to the 'Special' pump.

The pump-piston is of the 'bucket' type, namely, a piston packed with leather instead of steel spring-rings. In this respect it resembles the pumps previously noticed.

It is made in several types to suit varying duties. The two examples shown are suitable for heads up to 300 feet, and the steam-cylinder for steam pressures up to 100 lbs. per square inch. The long distance-piece

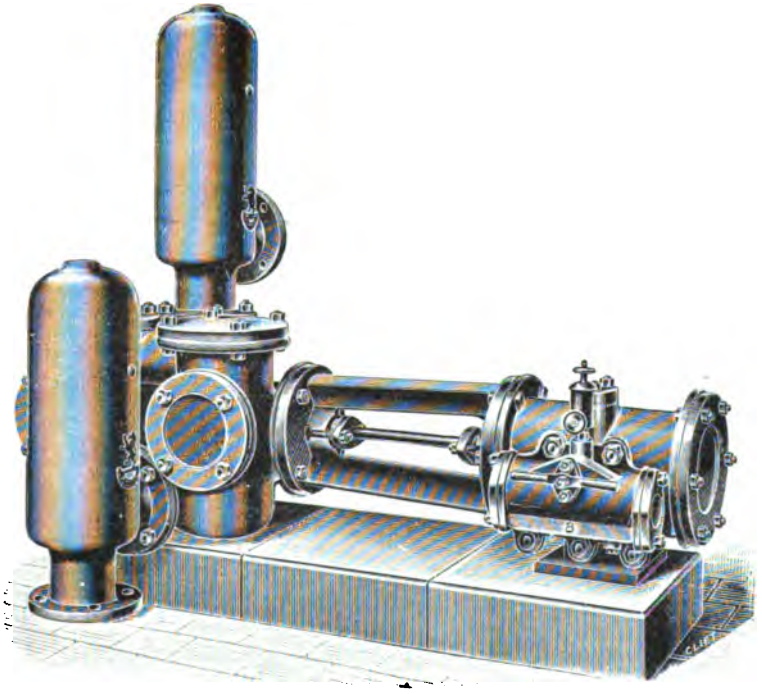


FIG. 77.—The 'Cornish' Piston-Pump—Bucket Type.

shown in fig. 77 admits of the piston making its full stroke without the pump end of the piston-rod entering the steam-cylinder, thereby preventing deleterious matter passing into the latter. The pumps are fitted with Evans's patent rotative disc valves; the seats are of gun-metal and the valves of rubber, rotative motion in which is produced by means of the inclination of the apertures in the seat impinging the water against the valve obliquely; this promotes its durability. The pump is made in sizes from 4 × 2 × 9 to 16 × 14 × 24. The following are standard sizes above 12-inch steam-cylinders.

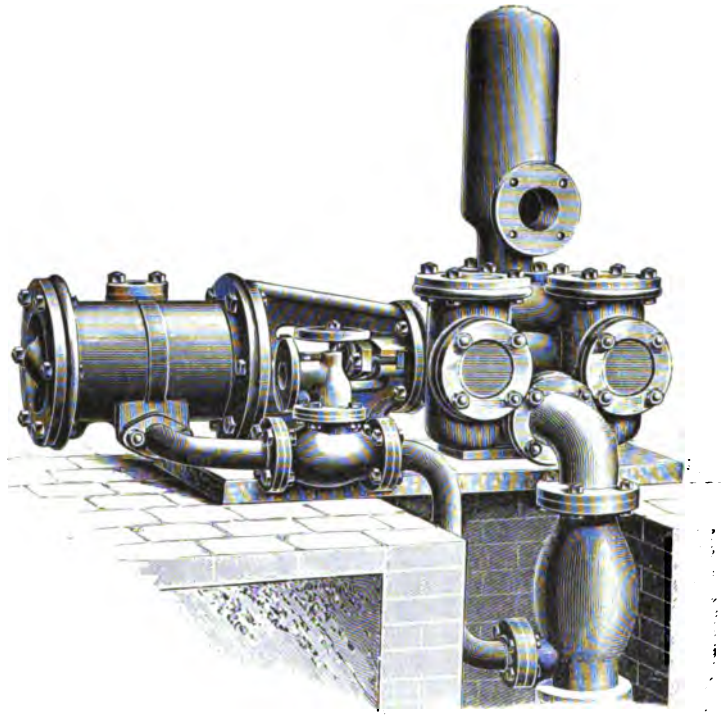


FIG. 78.—The 'Cornish' Piston-Pump—Bucket Type—with Suction-Pipe Condenser. The makers are Messrs. Jos. Evans & Sons, of Wolverhampton.

Dia. of steam cyl.	Dia. of pump	Length of stroke	Water per hour approx. at piston speed of 100 ft. per min.	Height water raised at 50 lbs. steam pressure	Dia. of suction and delivery pipes	Dia. of steam pipe	Dia. of exhaust pipe	Approx. length	Approx. width	Approx. height to top of air-vessel	Approx. weight
in.	in.	in.	gall.	ft.	in.	in.	in.	in.	in.	in.	cwt.
14	7	24	9,990	300	5	2⅓	3	110	32	56	25
14	8	24	13,050	234	6	2½	3	111	32	61	28
14	9	24	16,520	185	7	2⅔	3	114	32	70	32
14	10	24	20,400	150	8	2¾	3	116	32	72	35
14	11	24	24,680	124	8	2⅔	3	116	33	74	39
14	12	24	29,370	104	9	2½	3	117	34	87	43
14	14	24	39,980	75	10	2⅓	3	119	38	89	50
15	8	24	13,050	270	6	2½	3	114	33	61	30
15	9	24	16,520	212	7	2½	3	116	33	70	34
15	10	24	20,400	172	8	2½	3	119	33	72	38
15	11	24	24,680	142	8	2⅔	3	119	33	74	41
15	12	24	29,370	120	9	2⅔	3	119	35	87	45
15	14	24	39,980	87	10	2⅔	3	121	39	89	52
16	8	24	13,050	300	6	2½	3	114	35	61	31
16	9	24	16,520	242	7	2½	3	116	35	70	36
16	10	24	20,400	196	8	2½	3	119	35	72	40
16	11	24	24,680	162	8	2½	3	119	35	74	43
16	12	24	29,370	136	9	2½	3	119	36	87	47
16	14	24	39,980	100	10	2½	3	121	39	89	54

The 'Tipton' Piston-Pump.

In this pump, patented by Howl & Attwood, December 28, 1897, the steam-cylinder and valve-chest are self-draining throughout, an important factor, especially when motive steam or compressed air is conveyed a long distance from the generator, as is often the case in mines. This design ensures a dry cylinder without the aid of drain-cocks, and consequently secures a perfect cushion to the piston and often prevents a broken cylinder-cover, which otherwise may occur by a sudden rush of water in the steam-main caused by priming of the boiler or by other means. The steam-chest is placed on the side of the cylinder, so that the main steam-ports enter the

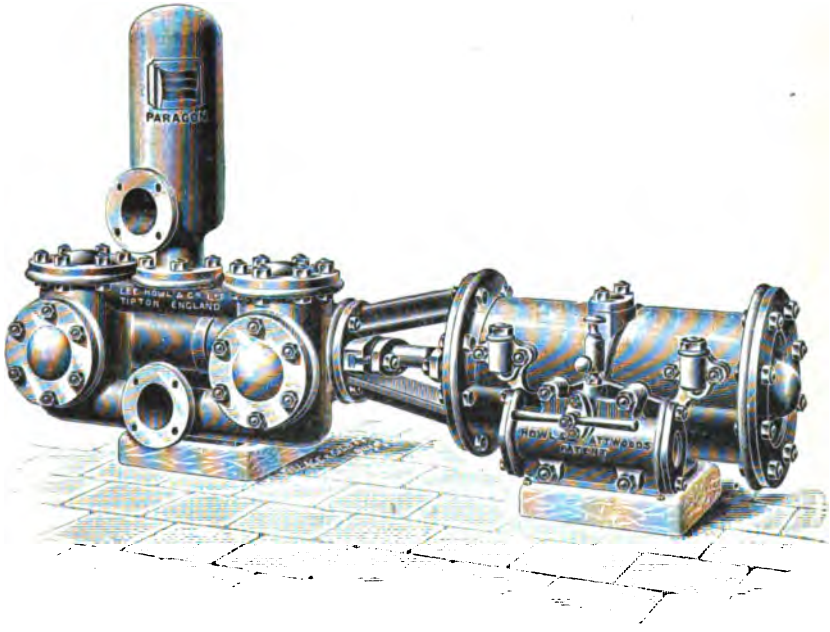


FIG. 79.—The 'Tipton' Piston-Pump.

lowest place in the bore of the cylinder, therefore all condensation drains to the exhaust by gravity. The exhaust-port for the piston-valve of the steam-chest is also at the lowest point, that it may be drained by gravity, and so derive all the benefits which accrue to the cylinder in like manner. Figuratively speaking the steam enters the cylinder on the top, then performs its duty and is exhausted underneath.

Fig. 79 is a perspective view of the 'Tipton' Pump (bucket pattern). Fig. 80 is a cross section through the steam inlet and exhaust passages of the cylinder. Fig. 81 is a longitudinal section through the steam-chest with the cylinder in elevation behind. Fig. 82 is a cross section through the auxiliary valve, steam-cylinder, and valve-chest, showing the passages which convey the

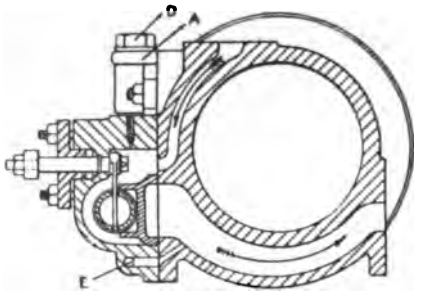


FIG. 80.

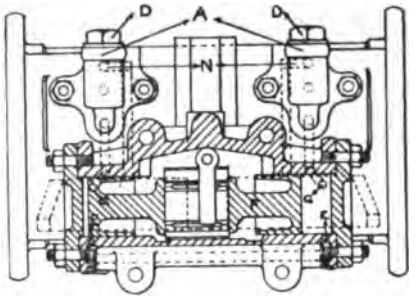


FIG. 81.

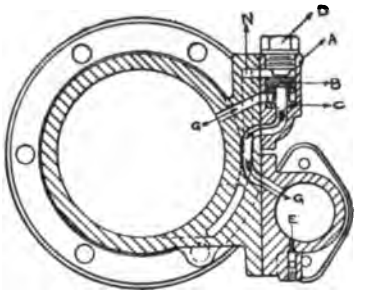


FIG. 82.

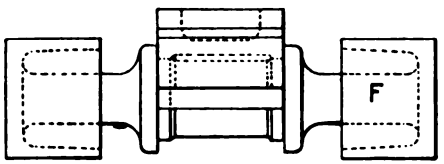


FIG. 87.

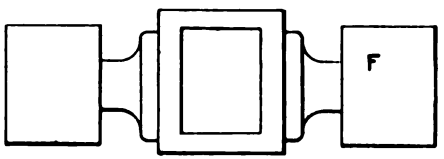


FIG. 88.

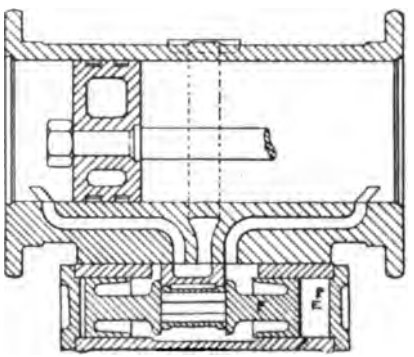


FIG. 83.

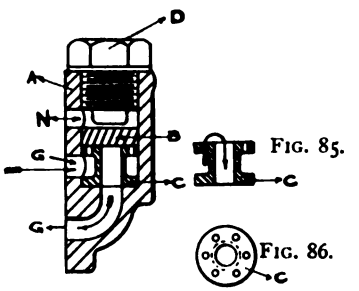


FIG. 84.

FIG. 85.

FIG. 86.

The 'Tipton' Piston-Pump. Cross sections of steam and exhaust passages and through the auxiliary valve, longitudinal sections of main cylinder and steam-chest, enlarged section of auxiliary valve, &c., and enlarged views of steam-chest plunger and slide-valve.

steam from the cylinder *viâ* the auxiliary-valve to the steam-chest to reverse the slide-valve. Fig. 83 is a section in plan through the cylinder and valve-chest, showing the main steam and exhaust ports, and fig. 84 an enlarged sectional view of the auxiliary valve. Figs. 85 and 86 are sections of the gun-metal bush in the auxiliary valve and a plan of the bush showing the annular row of holes. Enlarged views of the steam-chest plunger and slide-valve are given in figs. 87 and 88. A is the auxiliary valve casting, B the auxiliary valve which fits upon the face of the bush C; D, the stop or screwed plug which regulates the lift of the auxiliary valve A. E is the exhaust hole in the steam-chest for the plunger F; G is the live steam-passage for actuating the slide-valve plunger. The action of the valve gear may be thus described. When the piston passes the steam-passage G, live steam flows in the direction indicated by the arrows in figs. 81 and 82, which causes the auxiliary valve A to lift from the face of the bush, which then admits the steam down the centre of the bush and *viâ* the passages indicated to the front of the plunger in the steam-chest. When the slide-valve is thus reversed, steam is admitted from the cylinder-port through the passage N on to the top of the auxiliary valve A, which it holds down on the face of the bush during the time the piston is making its stroke and until the cylinder is exhausted. Makers, Lee, Howe, & Co., Ltd., Tipton.

THE 'UNIVERSAL' PISTON-PUMP.

Like the Worthington, Knowles, Blake, 'Special,' and other valuable direct-acting engines, this pump was invented in the United States, and has for its authors Messrs. Ezra Cope and James Riley Maxwell, of Cincinnati. It was patented in England September 15, 1868, since which time a great many improvements have been effected in it, and many thousands have been made by the well-known firm of Messrs. Hayward-Tyler & Co., London, the sole makers for this country.

There are two types of this engine—the long piston, short-stroke engine, and the short piston, long-stroke engine, each piston and ram of which has two forms of pumps. The ram-pumps will be considered in another section of this work.

The Short-Stroke Type.—This engine is represented by fig. 89, and in section by figs. 90, 91, and 92. There are two forms of water-chamber for this engine; that shown in fig. 89, in which the air-vessel is cast with the pump-chamber cover, is used with engines of from 4 inch to 9-inch steam-cylinders and 2-inch to 7-inch pumps; for engines of 9-inch to 21-inch steam-cylinders and 10-inch to 15-inch pumps, the air-vessel is a separate casting, bolted to the pump-chamber cover. It is used for lifts not exceeding 200 feet, and where very rapid action is desirable, as, for instance, for emptying wrecks, docks, etc., draining flooded mine-workings, and for any other purpose where the lift is comparatively low, the instantaneous reversing action of this pump gives it advantages which appear to be

possessed by very few pumps. It is largely and very successfully applied to raising sunken or sinking ships for salvage purposes. Pumps of 15-inch steam and water-cylinders, delivering from 70,000 to 80,000 gallons an hour, occupying a space of 36 square feet, have been used for work of this kind.

The illustrations referred to show that this pump has a very long steam-cylinder, and that, unlike all other machines of this class, it has no steam valve-chest nor any appearance of valve gear external to the cylinder, but that in lieu thereof it contains a unique piston of considerable length, within which is enclosed the valve necessary for imparting motion to the

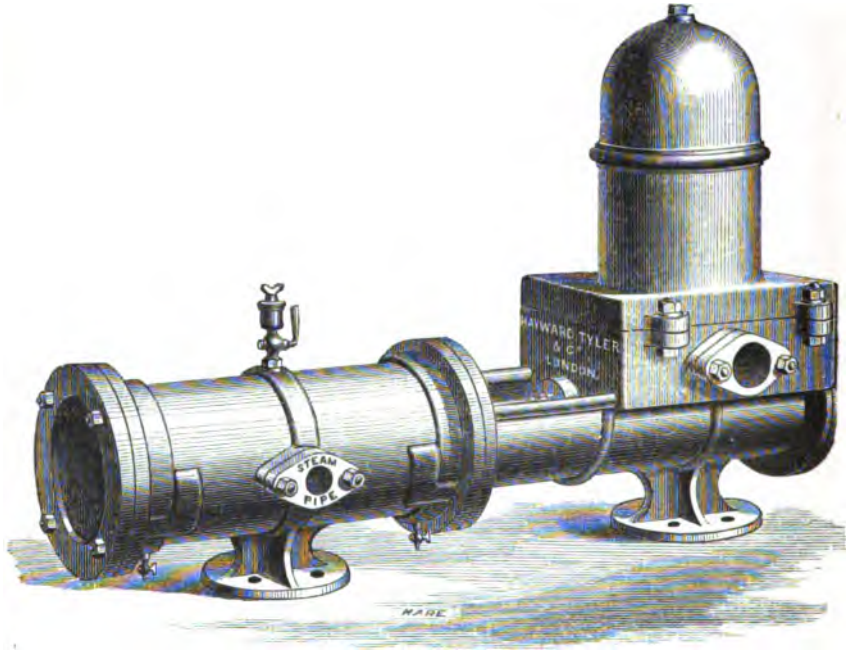
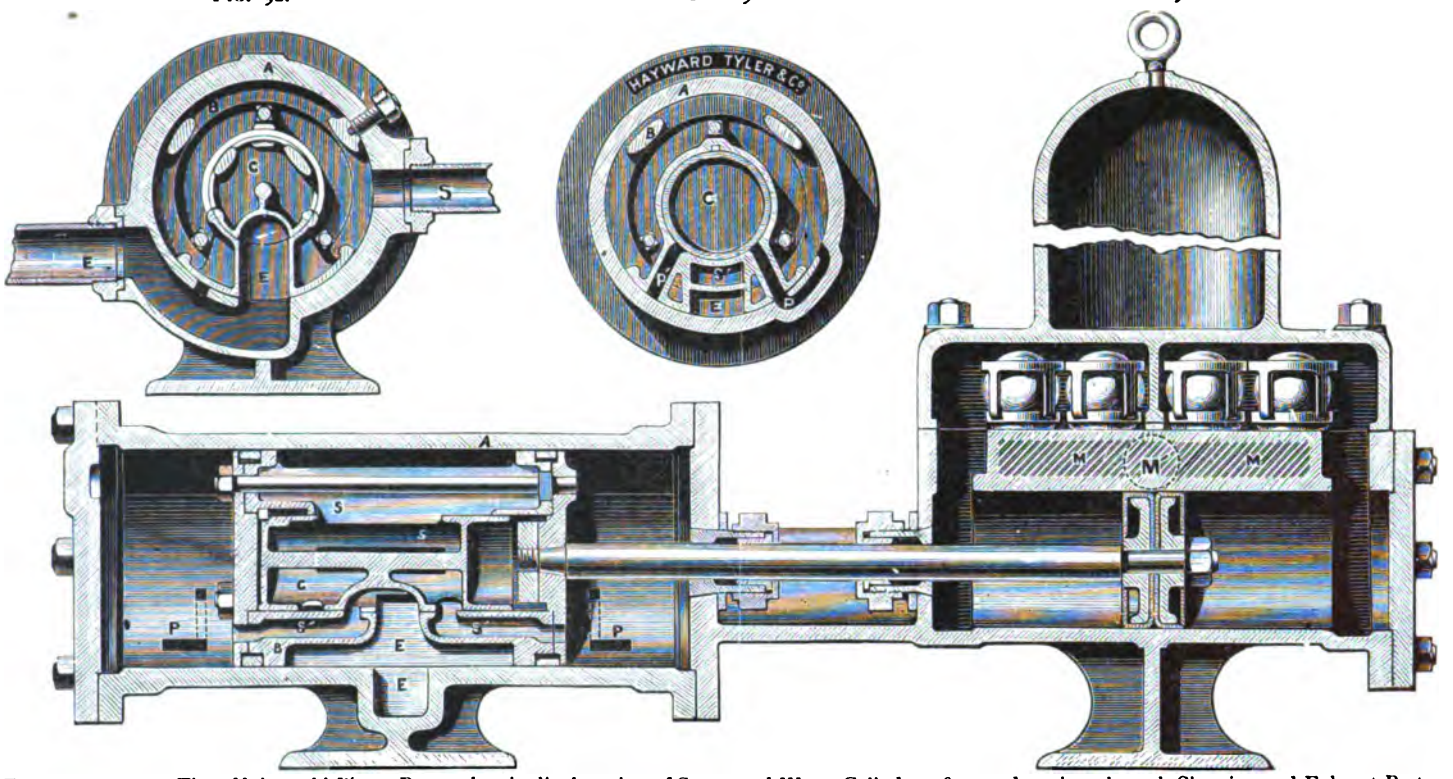


FIG. 89.—The 'Universal' Piston-Pump.

engine. Fig. 90 is a sectional elevation of the steam and water-cylinders and their contents, and gives a very good idea of this machine; fig. 91 a section through the shooting or valve-moving ports; fig. 92 a section through the exhaust port. India-rubber disc-valves were formerly used, but have been discarded in favour of solid rubber ball-valves, which are available for heads up to 200 feet. For greater heads the gun-metal mitre-valves are used. As the action of this engine is rather difficult to understand, a minute description is given of the details and their functions, in order that the patient reader may be able to follow the movements of the different parts as afterwards explained.

FIG. 92. FIG. 91. FIG. 90.



FIGS. 90, 91, 92.—The 'Universal' Piston-Pump; longitudinal section of Steam and Water-Cylinders, &c., and sections through Shooting and Exhaust Ports.

The steam-cylinder is a plain barrel with a steam branch on one side, midway between the two ends, and an exhaust branch on the other side and opposite, which communicates with the bottom of the cylinder. Near each end of the cylinder on the same side, and midway between the top and bottom, is a steam shooting-port, communicating by a passage with a long horizontal slot, admitting steam to one end of the valve-chamber. Midway between these slots, but on the opposite side of the cylinder, is the exhaust slot, communicating alternately with each end of the valve-chamber by corresponding exhaust ports on the opposite side. The piston is packed at each end with ordinary packing-rings. The covers of the piston are held together by bolts. A guide-pin, screwed into the cylinder and fitting a corresponding groove in the piston, prevents the latter from rotating. The length of the piston between the inner side of the ends must be equal to the length of the stroke in addition to the steam inlet. The body or outer shell of the piston between the two ends is quite open at the top and sides, except where two comparatively narrow distance-pieces near the top run the whole length of the piston. The bottom part, in which are two steam ports and the exhaust port, works steam-tight on the cylinder. In the centre of the piston body is a cylindrical valve-chamber in which a long piston constituting the slide-valve works. A guide-pin in the valve, which works in a groove in the valve-chamber, prevents it from turning. There are no moving parts in the engine except the piston B and the cylindrical piston-valve C (fig. 90). The piston B, being longer than its stroke, allows the steam to enter at all times, so that steam, S, is always on in the interior of the piston and piston-valve. The latter has a 'D' cavity in the middle, which alternately connects each end of the cylinder with the main exhaust E, by the passages S'. In the position shown in the drawing, the piston is travelling towards the reader's left hand, the steam entering the right-hand end of the cylinder through the right-hand passage S', while the left-hand end is exhausted through the left-hand passage S'. When the piston passes over the port P (left hand), the steam from the inside of the piston passes through the port and passage, P, to the left-hand end of the piston valve-chamber, while a corresponding port, P' (fig. 91), is opened to the exhaust, and thus the piston-valve is reversed by the action of the steam alone, the ports being so arranged that the piston is cushioned at the end of its stroke: thus these pumps will run at a very high or very low speed.

In the pump, M shows the suction cavity, and M' the suction opening, the delivery opening corresponding on the other side.

2.—SINGLE STEAM-CYLINDER, NON-EXPANSIVE, NON-CONDENSING ENGINES WORKING DOUBLE-ACTING RAM PUMP.

As the steam-cylinder and valve arrangements of the engines which we shall give, answering to the above heading, are, with two exceptions, identical with those already described, being, in fact, the same engines with a ram or plunger instead of a piston attachment, it will only be necessary, except in the cases named, to describe the hydraulic parts.

In one of the examples given (fig. 111) the engine is shown with a condenser.

It has already been observed in a previous section that these pumps may be either internally or externally packed; those that are externally packed ('outside-packed plunger-pumps,' as they are called) may be resolved into those which are packed at the centre; that is, the plunger (which is double-acting) works through a central stuffing-box, hence the appellation 'outside centre-packed plunger-pumps,' and those pumps which have two single-acting plungers, delivering from their inside ends and working through a stuffing-box at each end of the pump-barrel.

For the sake of method we shall consider the pumps in the following order:—

I. Internally packed (one double-acting plunger).

II. Externally packed.

a, centre-packed (one double-acting plunger).

b, outside-packed (two single-acting plungers).

The 'Universal' Plunger-Pump.

This is an adaptation of the 'Universal' long-cylinder short-stroke engine, already described, to a plunger-pump; it belongs to Class I, and will be the only example submitted, as the pumps of this class are not specially adapted for mining purposes. Preference is given to pumps that are outside-packed, where any leak or defect is easily seen and quickly remedied. To get at the stuffing-box, which is located near the centre of the pump, it is necessary to remove the bonnet.

Fig. 93 is a longitudinal section of the water-cylinder, valve-chambers, plunger, etc.; fig. 94 is a plan, with the valve-chambers in section, the air-vessel, and valve-chamber cover, cast in one, being removed, and fig. 95 is an end elevation with the bonnet removed. It will be observed that the plunger is a hollow one, the piston-rod, C, being screwed to the solid end.

In the illustrations 1 denotes the plunger-case or working-barrel; 2, the stuffing-box; 3, the plunger; 4, the bonnet, otherwise plunger or ram chamber.

The standard sizes range from 5-inch steam-cylinder and 3-inch plunger to 21-inch steam-cylinder and 10-inch plunger.

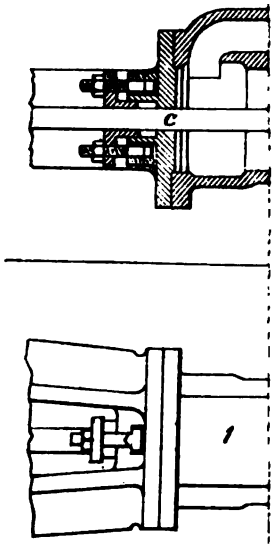
Pumps of this class are not suited for bad mine water or for heavy duties. We shall notice presently another pump—the 'Niagara'—by the same makers, Messrs. Hayward-Tyler & Co., London, which is a superior pump for mines.

The following is a description, taken from the specification filed in the Patent Office, of the valve gear which has been patented by Mr. R. L. Howard, senior partner of the firm, and which is applicable to large engines of the 'Universal' long-stroke class, as well as to compound engines, in the same way as the valve gears of Messrs. Cope and Maxwell and Mr. Henry Davey.

'Heretofore the movement of direct-acting steam engines has in various ways been controlled or regulated according to the varying load thereon by means of valve gear, wherein the main valve is worked by an auxiliary steam-cylinder controlled by a cataract or other governor, and receiving a secondary motion from some moving part of the engine or by an expansion valve working in an opposite direction to the main slide-valve, and controlled indirectly by a cataract.

'Now the object or purpose of this invention is to control or regulate direct-acting steam engines according to the varying load by means of valve gear, wherein the expansion valve is worked from the main steam piston, the main valve being worked by a subsidiary piston controlled by a cataract or other governing appliance, all operating as hereinafter described.

'For this purpose I employ by preference an ordinary D-shaped main slide-valve with ports passing through it, and I work an expansion valve on it. The main slide-valve is moved by means of an auxiliary steam piston, controlled by a cataract in a well-known manner. The expansion slide-valve is worked from the main steam piston in the same direction and in unison therewith, but with a shorter stroke, the necessary connection being by a system of levers and connecting rods, or any other well-known device for imparting the motion to the expansion valve, the latter being moved in unison with the main piston for the purpose in view, and operating in such a manner that when the load on the engine is lessened, and the tendency of the engine is to quicken its speed, the expansion valve acting in unison also quickens its speed in the same ratio as the main piston; but the main steam-valve continuing to move at the speed regulated by the cataract, the expansion valve will overrun it, and cut off the steam. On the other hand, if the load on the engine is increased and the tendency of the main piston is to run slower, the expansion steam valve will decrease its speed in the same ratio, but the main valve (continuing to work at the speed regulated by the cataract) will overrun the expansion valve, and will thus admit more steam as required.



FIGS

'This motion may be applied to direct-acting engines for various purposes, for which such engines are now applicable. It may also be applied not only to ordinary slide-valves, as here more particularly described, but also to rotary and other valves.

'Figs. . . . . [96 and 97] show one modification of my improvements in valve gear, wherein the expansion or regulating valve, E, receives its motion from the main piston by means of levers, as represented, and the main valve, D, receives its motion by the direct pressure of steam in the valve moving or auxiliary cylinder, C'. The motion of the main valve is regulated by the ordinary cataract, H, through its piston, G, and rod, D''. A is the main steam-cylinder; B, the main piston; and C, the steam-chest; D is the main valve moved, as before stated, by the direct pressure of steam upon the valve-moving piston; D' is the auxiliary cylinder; E is the expansion or governing valve worked on the top of the main valve, D, and moved by motion taken from the main piston-rod through the arm, J, link I'', lever I, and rod I', as before mentioned; F is the auxiliary valve of the B form, and provided with double cavities, *h*, *h*, for admitting and exhausting steam from the auxiliary or valve-moving cylinder, C', for moving the main valve, D, in the right direction; it is operated by the contact of the lever, I, with the tappets, *k*, *k*, upon the rod, K.

'In operating the valves the lever first moves the auxiliary valve, F, admitting steam to the valve-moving cylinder, C'. The valve, D, is then moved until it establishes communication between the steam and exhaust ports, A', B', through the cavity, *b*, and brings one of the ports, *a*, into communication with the other main steam port, A', and with the cavity under the valve, D. High steam then passes through the ports, *a* and A', in the valve, D, to one end of the cylinder, and is exhausted from the other end through ports, A', B', and cavity, *b*. The main piston then commences its motion, and if it move at the same relative velocity as the valve-moving piston, the relative position of the valves will be unchanged, and the admission of steam will be uniform; but, if the speed of the main piston becomes greater or less than that of the valve-moving piston, the lever will at once begin to act on the valve, E, cutting off or admitting a larger supply of steam, as may be required, the cut-off valve, E, producing the governing or regulating motion, as hereinbefore described.'[1]

THE 'CAMERON' PLUNGER-PUMP.

Fig. 98 is an elevation of this pump, which belongs to Class II *a*, and is a very good specimen of a mining pump. The makers, the A. S. Cameron Steam Pump Co., East 23rd Street, New York, introduce it in the following terms:—

'This pump, for mining purposes, has earned for itself a world-wide

[1] 'Specification filed by Robert Luke Howard, of Tottenham, in the County of Middlesex, in the Great Seal Patent Office, on March 13, 1877.'—*Improvements in Valve Gear for Direct-acting Steam Engines.*

reputation, and in this department we can confidently say it stands pre-eminent. Our new patterns embody all improvements that years of experience in this class of work could suggest; all parts are easily got at, the seats for the water valves are of the best composition, the openings large, and the valves easily removed; there are no valve bolts to become loose;

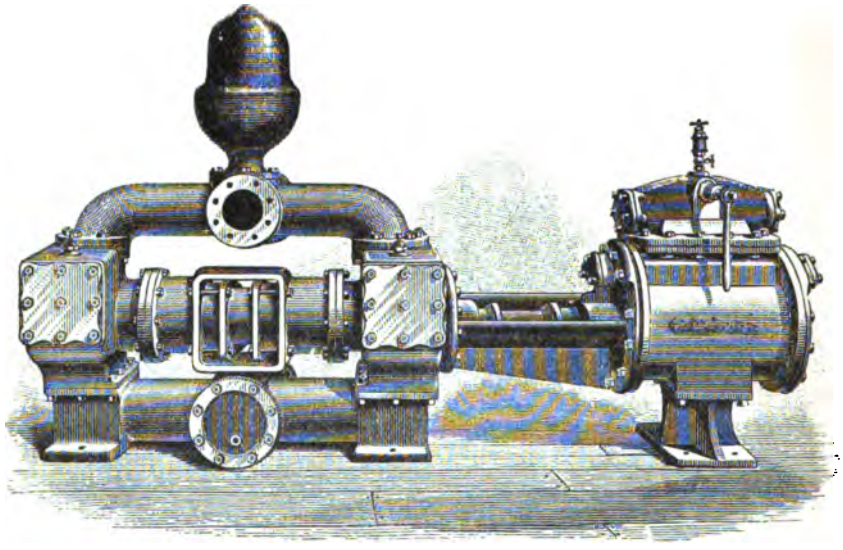


FIG. 98.—The 'A. S. Cameron' Plunger-Pump.

the plunger being supported in both packing-boxes cannot sag or get out of line at the ends of the stroke, and there is not a single working part exposed to damage by either carelessness or accident. As adapted to this purpose its merits are at once appreciated by practical men.'

Dia. steam cylinder	Dia. of plunger	Length of stroke	Capacity per stroke	Approximate water per hour at ordinary speed	Dia. suction pipe	Dia. delivery pipe	Dia. steam pipe	Dia. exhaust pipe
in.	in.	in.	gall.	gall.	in.	in.	in.	in
14	9	33	9·07	21,000	8	6	2	3
16	9	33	9·07	21,000	8	6	2½	4
18	9	33	9·07	21,000	8	6	3	4
16	10½	33	12·37	27,000	10	8	2½	4
18	10½	33	12·37	27,000	10	8	3	4
20	10½	33	12·37	27,000	10	8	3	4
18	12	36	17·63	34,500	12	10	3	4
20	12	36	17·63	34,500	12	10	3	4
22	12	36	17·63	34,500	12	10	4	5
24	12	36	17·63	34,500	12	10	4	5
24	14	36	24·00	48,000	12	10	4	5
26	14	36	24·00	48,000	12	10	5	6
28	16	36	31·32	60,000	14	12	5	6
30	16	36	31·32	60,000	14	12	5	6

The 'Cornish' Plunger-Pump.

The illustration given (fig. 99) represents a suitable pump for heads up to 300 feet, and the steam-cylinder for steam pressures up to 100 lbs. per square inch. The pump is fitted with Evans's patent rotative disc valves. The makers are Messrs. Jos. Evans & Sons, Wolverhampton.

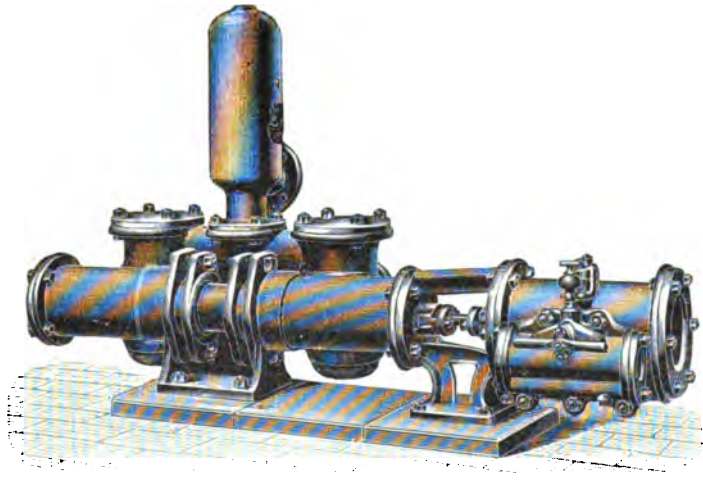


Fig. 99.—The 'Cornish' Plunger-Pump.

The standard sizes are as under; the stroke is 12 inches in each case. The capacity, dimensions, etc., are given.

Dia. steam-cylinder	Dia. plunger	Water per hour (approx.) at 100 feet per minute piston speed	Height water raised with 50 lbs. steam	Dia. suction and delivery pipes	Dia. steam pipe	Dia. exhaust pipe	Approx. length	Approx. width	Approx. height to top of air-vessel	Approx. weight
in	in.	gall.	ft.	in.	in.	in.	in.	in.	in.	cwt.
5	4	3,260	119	3	$\frac{3}{4}$	1	77	16	37	7
5	5	5,100	75	$3\frac{1}{2}$	$\frac{3}{4}$	1	77	18	43	$9\frac{1}{2}$
5	6	7,340	53	$4\frac{1}{2}$	$\frac{3}{4}$	1	79	20	42	$10\frac{1}{4}$
5	7	9,990	39	5	$\frac{3}{4}$	1	81	23	47	$12\frac{3}{4}$
5	8	13,050	30	6	$\frac{3}{4}$	1	82	26	53	$15\frac{1}{4}$
6	4	3,260	172	3	$\frac{3}{4}$	1	77	16	37	$8\frac{1}{4}$
6	5	5,100	110	$3\frac{1}{2}$	$\frac{3}{4}$	1	77	18	43	10
6	6	7,340	75	$4\frac{1}{2}$	$\frac{3}{4}$	1	79	20	47	$12\frac{1}{4}$
6	7	9,990	56	5	$\frac{3}{4}$	1	81	23	47	$13\frac{3}{4}$
6	8	13,050	43	6	$\frac{3}{4}$	1	82	26	53	16
7	4	3,260	234	3	$1\frac{1}{4}$	$1\frac{1}{2}$	78	18	37	9
7	5	5,100	150	$3\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$	78	18	43	$10\frac{1}{2}$
7	6	7,340	104	$4\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$	81	20	47	$12\frac{1}{2}$
7	7	9,990	75	5	$1\frac{1}{4}$	$1\frac{1}{2}$	82	23	53	16
7	8	13,050	58	6	$1\frac{1}{4}$	$1\frac{1}{2}$	83	26	53	$16\frac{3}{4}$
8	4	3,260	300	3	$1\frac{1}{4}$	$1\frac{1}{2}$	78	19	37	$9\frac{1}{2}$
8	5	5,100	196	$3\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$	78	19	43	11

Dia. steam cylinder	Dia. plunger	Water per hour (approx.) at 100 feet per minute piston speed	Height water raised with 50 lbs. steam	Dia. suction and delivery pipes	Dia. steam pipe	Dia. exhaust pipe	Approx. length	Approx. width	Approx. height to top of air-vessel	Approx. weight
in.	in.	gall.	ft.	in.	in.	in.	in.	in.	in.	cwt.
8	6	7,340	136	4½	1¼	1½	81	20	47	13
8	7	9,990	100	5	1¼	1½	82	23	53	16½
8	8	13,050	75	6	1¼	1½	83	26	59	19
9	5	5,100	248	3½	1½	1½	82	21	43	12
9	6	7,340	172	4½	1½	2	85	21	47	15
9	7	9,990	126	5	1½	2	86	23	53	18
9	8	13,050	97	6	1½	2	87	26	59	20½
10	5	5,100	300	3½	1½	2	83	23	43	13¼
10	6	7,340	212	4½	1½	2	85	23	47	16½
10	7	9,990	156	5	1½	2	87	23	53	19
10	8	13,050	119	6	1½	2	88	26	59	21½

The 'Selden' Plunger-Pump.

It may be mentioned as a noteworthy feature of this pump (fig. 100) that the upper and lower valve-chambers are cast in separate parts, and

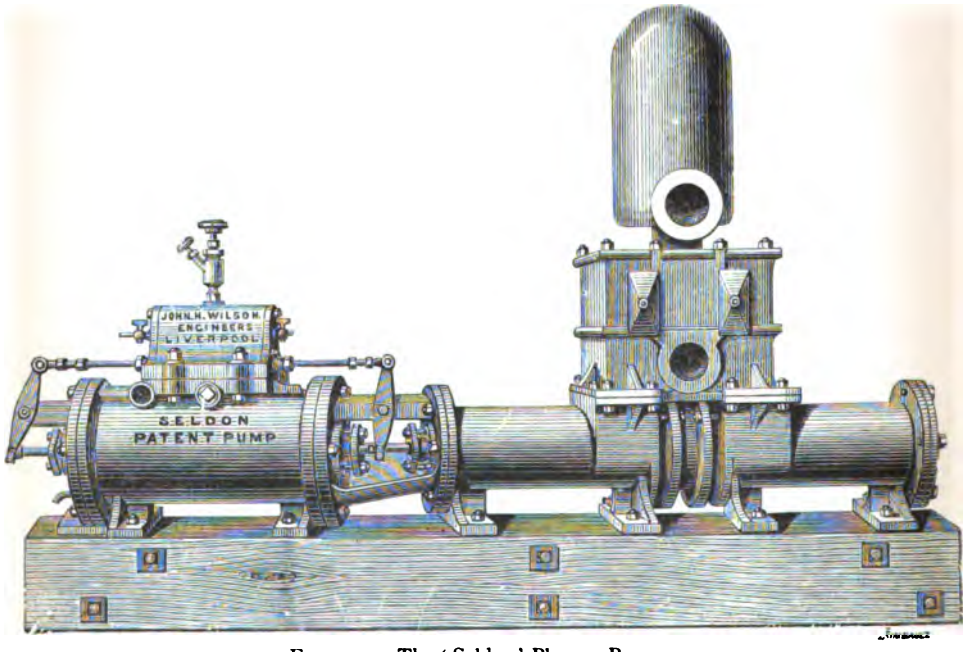


Fig. 100.—The 'Selden' Plunger-Pump.

have the plate upon which is the valve-seat between them, the whole being securely bolted together; should any accident occur to the seat-plate,

it can be readily taken out and repaired or renewed without the loss of any other part.

The valves are all made so large that by lifting from $\frac{3}{8}$ths of an inch in the smaller sizes to $1\frac{1}{4}$ inch in the larger sizes they will give the full capacity of the suction and discharge pipes. The action of the valves is said not to be audible with the ear upon the valve-chamber, when working under a test pressure of 350 feet.

The makers, Messrs. J. H. Wilson & Co., Liverpool, say: 'The "Selden" pump has often been run with water instead of steam, and it will run as steadily and reverse as promptly as with steam. When under water it will work well. On one occasion, there being no steam for several days, owing to the boilers giving out, the mine was flooded, yet as soon as steam was let down the pump started promptly, and was run at a higher rate of speed than it had ever been run at before.'

THE 'NIAGARA' PLUNGER-PUMP.

Of the various forms of pumps which Messrs. Hayward-Tyler & Co. manufacture, the above is *par excellence* the pump for mine and colliery use, particularly for heavy lifts, and may be used for heads up to 1,000 feet. Figs. 101 and 102 are a plan and elevation of this well-known engine. Figs. 104 to 107, which are views of the self-governing engine, show the arrangement of the pump, the same kind of pump being used with both engines.

It will be observed that this engine has a long hollow ram working into two ram-cases and fitted with two outside stuffing-boxes, as all underground engines should be. The suction and delivery-valve boxes are shown at 4.4 and 5.5 respectively; 1.1 are the ram-cases and 2.2 the stuffing-boxes. We must refer the reader to pages 101 and 102 for examples of work done by the 'Universal' engines in collieries.

Messrs. Hayward-Tyler & Co.'s list enumerates sizes varying from a 12-inch steam-cylinder and 4-inch ram to a 33-inch steam-cylinder and a 12-inch ram, but the largest size made in this form has been a 26-inch steam-cylinder and 10-inch ram; though they have made their long-piston short-stroke engines with 33-inch cylinders, and several on a rather different plan with cylinders of 40 inches and rams of 10 inches diameter.

Referring to the different types of this firm's engines for underground drainage, Mr. Fell, in his paper on 'Direct-acting Steam-Pumping Machinery,'[1] remarks as follows: 'It may be interesting to detail some of the most suitable applications of these pumps (the short and long-stroke types). They have been found most exceptionally efficient under the

[1] Read before the South Staffordshire and East Worcestershire Institute, February 19, 1877.

most extreme diversity of lifts, from 10 feet to 600 feet, but it must be remembered that the conditions of success for such different pressures depend upon very widely diverse data. Under the low lifts, up to 20 or 30 feet, the most elastic class of pump-valves must be used, so as to ensure the least noise and wear and tear under high piston speeds. The lift of these valves must also be low, and should be distributed over a large space. This requirement has been admirably met by Messrs. Hayward-Tyler's arrangement of multiple india-rubber ball-valves, of which a specimen, which has been subjected to many months' wear, is laid before you. It will be found that this valve has actually lost one-eighth of an inch in wear all over the ball so uniformly that its shape is not altered, nor is it marked in any way.

'Under these low lifts as much as 250 to 300 feet piston speed can be obtained from Hayward-Tyler's "Universal" pumps, so elastic and lively is their action. Amongst the higher lifts, up to 60 or 70 feet, may be reckoned most of the applications to the ordinary factory, household, brewers', and small water-supply purposes, and up to about 150 or 200 feet the same multiple india-rubber valve-system is most successfully used.

'Ranging upwards from these lifts to 600 feet vertical and more are the heavy colliery lifts. For these higher lifts a very different form or construction must be adopted. The piston speed must be much reduced, and can seldom run more than 100 to 120 feet per minute. The india-rubber valves are no longer serviceable, at any rate in their original ball form, and either hard rubber-discs [1] or gun-metal valves must be used. In each case the lift of the valves must be very small, to reduce the shock of the reversal of the stroke, and for that reason also the reversals should be as few as possible, as long strokes are advisable for high lifts. The system of a double plunger-pump is most approved for the deep lifts, in which the plunger is made tight by two outside packing-glands, packed with ordinary hemp.

'Out of many testimonials of their efficiency under such circumstances the writer need only mention one or two, such as a 20-inch cylinder with a 6-inch double-acting plunger-pump throwing 3,500 gallons per hour a height of 400 feet vertical, at a slow speed, in the Foxhole Collieries of the Patent Anthracite Coke Company; also at the Yate Collieries a 15-inch cylinder and 4-inch pump, throwing 2,500 gallons per hour, at a slow speed, to a height of 480 feet.' [2]

The following are some of the regular sizes of the 'Niagara' pump.

[1] The rubber-disc valves have been discontinued, being inadequate for high lifts.

[2] The number of strokes per minute was 30, the steam-pressure 30 lbs. per square inch, and the distance of the boilers from the pump 340 yards. A further testimonial after five years' work states thus: 'We have never experienced any break-down, although the pump has been in constant work during the whole five years, and only a very small sum has been expended in repairs.'

Dia. of steam cylinder	Dia. of pump plunger	Length of stroke	Approx. water per hour piston speed 100 feet per minute	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Total length	Total width	Wgt. approximate
in.	in.	in.	gall.	in.	in.	in.	in.	ft. in.	ft. in.	cwt.
12	4	24	3,200	3	3	2½	3	11 6	3 6	35
12	5	24	5,000	3	3	2½	3	11 6	4 3	38
12	6	24	7,200	4	4	2½	3	11 6	4 9	49
12	8	24	12,800	6	6	2½	3	11 6	5 6	68
12	8	36	12,800	6	6	2½	3	14 6	5 6	76
12	10	24	20,000	8	8	2½	3	11 6	5 9	93
15	4	36	3,200	3	3	3	4	14 6	3 6	46
15	5	36	5,000	3	3	3	4	14 6	4 3	51
15	6	36	7,200	4	4	3	4	14 6	4 9	62
15	8	36	12,800	6	6	3	4	14 6	5 6	83
15	10	36	20,000	8	8	3	4	14 6	5 9	109
15	10	48	20,000	8	8	3	4	18 0	5 9	118
18	4	36	3,200	3	3	3½	4½	14 9	3 6	55
18	5	36	5,000	3	3	3½	4½	14 9	4 3	58
18	6	36	7,200	4	4	3½	4½	14 9	4 9	70
18	8	36	12,800	6	6	3½	4½	14 9	5 6	91
18	10	36	20,000	8	8	3½	4½	14 9	5 9	118
21	4	48	3,200	3	3	4	5½	18 0	3 6	70
21	5	48	5,000	3	3	4	5½	18 0	4 3	74
21	6	48	7,200	4	4	4	5½	18 0	4 9	87
21	8	48	12,800	6	6	4	5½	18 0	5 6	109
21	10	48	20,000	8	8	4	5½	18 0	5 9	138
26	5	60	5,000	3	3	4½	6½	21 0	4 3	108
26	6	60	7,500	4	4	4½	6½	21 0	4 9	121
26	8	60	12,800	6	6	4½	6½	21 0	5 6	146
26	10	60	20,000	8	8	4½	6½	21 0	5 9	175

DAVEY'S 'DIFFERENTIAL' PLUNGER-PUMP.

This engine (fig. 103) is another example of Class II *a* (outside centre packed), and is made in sizes varying from 10 to 40-inch steam-cylinders; the largest made appears to have been one of 52-inch cylinder. The plungers vary in size from 4 to 12 inches in diameter, with a stroke of from 2 to 5 feet. Any combination in the sizes of the cylinder and rams and the length of the stroke can, of course, be made. When a condenser is used, the steam is condensed by means of a patent separate condenser, the air-pump of which is sometimes worked by the pressure of water in the main column.

The engine is fitted with Davey's Patent 'Differential' valve gear, which will be fully described in the section dealing with compound engines.

The engine and pump stand upon one bed-plate; in one of the designs of the condensing engine, the engine, pump, and condenser are placed upon the same bed-plate. The type of engine for pumping gritty water is much more expensive than that required for clean water.

The following are particulars of work done by engines of this class in collieries:—

One engine with 12-inch cylinder, 15-inch stroke, to raise 6,000 gallons per hour 300 feet.

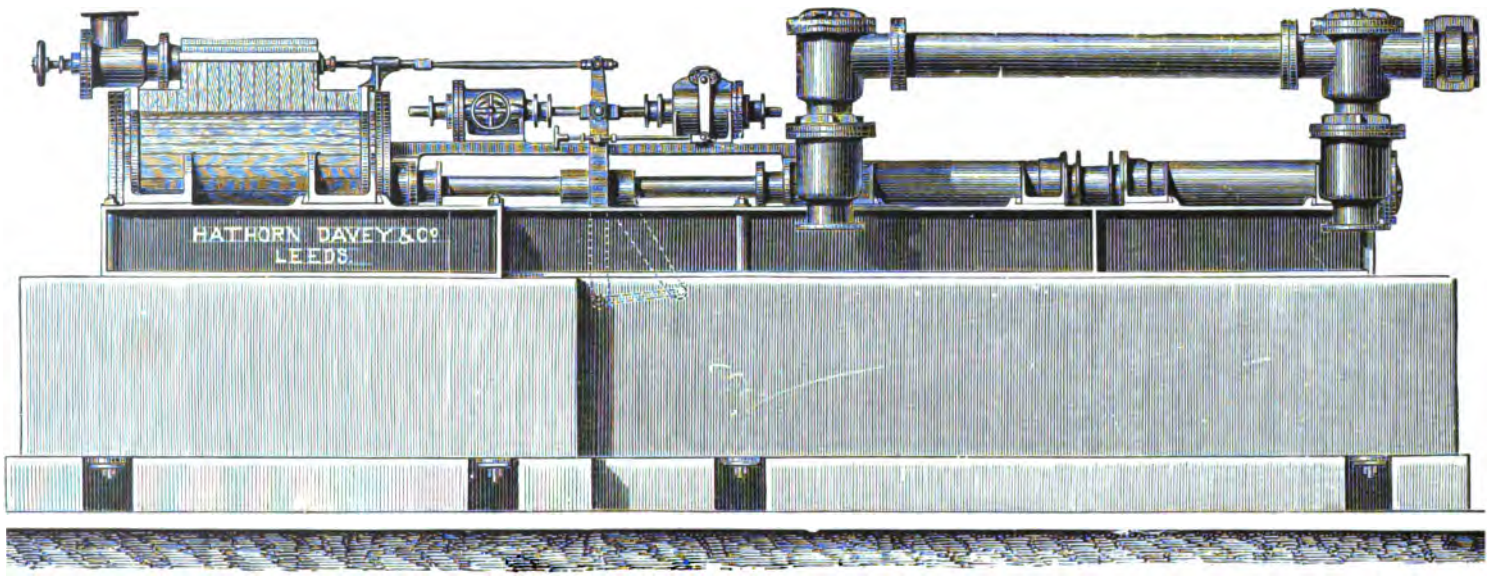


FIG. 103.—Davey's 'Differential' Plunger-Pump.

One engine with 14-inch cylinder, 20-inch stroke, to raise 8,000 gallons per hour 190 feet.

One engine with 14-inch cylinder, 20-inch stroke, to raise 8,800 gallons per hour 320 feet.

Two engines with 20-inch cylinders, 36-inch stroke, to raise 6,000 gallons per hour 1,000 feet.

The subjoined table gives examples of sizes, capacities, etc. :—

Dia. of steam cyl.	Dia. of plunger	Length of stroke	Water per hour	Height water can be raised with 40 lb. boiler pressure	Dia. of suction and delivery pipes	Dia. of exhaust pipe	Dia. of steam pipe
in.	in.	in.	gall.	ft.	in.	in.	in.
10	4	36	3,837	400	3	2½	1½
12	4	36	3,837	575	3	2¾	2
14	4	36	3,837	778	3	3	2½
16	4	36	3,837	1,024	3	3½	2¾
18	4½	36	4,860	1,015	3½	4	3
20	5	48	6,997	1,019	4	4½	3½
22	5½	48	9,097	1,020	4¾	5	3½
24	6	48	10,080	1,027	5	5½	4
26	7	48	13,692	870	5¾	6	4½
28	7	60	15,648	1,010	6¼	6¼	4½

The makers are Messrs. Hathorn, Davey, & Co., Leeds.

THE 'SELF-GOVERNING' PLUNGER-PUMP.

The self-governing motion of the valve gear, which is the peculiar feature of this engine, is the invention of Messrs. Cope and Maxwell. The engine is constructed in two forms; one in which both the cataract and the valve-moving cylinder travel, and in the other the valve-moving cylinder is stationary and only the cataract cylinder travels. 'The self-governing motion was introduced to ensure economy of fuel, to procure a positive motion of the valves at all times, and for regulating the motion of the main piston under all circumstances to which pumping engines are subject, by suddenly increased or diminished load on the pump or pumps, and thereby render the engine safe under variable loads, by varying the pressure of steam in the main steam-cylinder or cylinders, according to the load or resistance against which the piston works. This is accomplished by actuating the main slide-valve of the engine by the combined motion of a valve-moving cylinder and a valve-moving piston. The valve-moving cylinder receives its motion from the main piston of the engine by means of levers, and consequently has a motion which varies with the velocity of the main piston. The valve-moving piston is actuated by the direct pressure of steam, and has its motion controlled and rendered constant by a cataract governor. The valve-moving cylinder and valve-moving piston travel in opposite directions, the one acting upon the main valve to cause it to open the steam ports, and the other to shut off the admission of steam. The resultant of these two motions is to cause a motion of the main slide-valve,

which varies with every minute increase or decrease of the resistance of load upon the main piston.'[1]

In the arrangement of the valve gear, to which the accompanying illustrations and the following description refer, both the valve-moving cylinder and the cataract-cylinder (or governor) travel.

Fig. 104 is a perspective elevation, fig. 105 a longitudinal section, fig. 106 a plan, and fig. 107 a transverse elevation of an engine with a double-acting ram-pump. It consists of one main horizontal cylinder, mounted upon a cast-iron bed-plate, with steam and exhaust ports, and D slide-valve of the ordinary type; one steam-starting cylinder and one cataract cylinder, mounted upon an entablature in the centre line of the main slide-valve spindle, the piston-rods of which are a continuation of the same. The special feature of this machine is the self-governing valve arrangement. A is the main cylinder, provided with the usual steam and exhaust ports and passages; B, the main piston; C, the valve chest; D is the main slide-valve of the ordinary D type. E is the valve-spindle, which is prolonged, and also acts as the rod for the valve-moving piston, F, and the cataract piston, G; Q is the valve-moving cylinder, on the top of which is a small valve-chest, H, in which works a supplementary valve, I; this valve admits steam alternately on either side of the valve-moving piston, F. N is the supplementary valve-spindle, which is provided with two tappets, O; and on the end of this spindle provision is made for the starting-handle, shown in plan, fig. 106; J is a pipe admitting steam from the main valve-chest to the valve-moving cylinder-chest, and K is a pipe leading from the valve-moving cylinder to the main exhaust, L; these pipes work in glands, shown in the plan. The cataract governor, P, consists of a plain cylinder, with a port or passage leading from one end of the cylinder to the other; and an adjusting plug is fitted in the middle of this passage, for regulating the speed of the valve-moving piston, and consequently the main slide-valve, which is attached to the same rod; R is the main levers, working on a fulcrum, S. The bottom ends of these levers are, by the two links, T, connected to a horn or arm, U, which is fastened to the main piston-rod, V, with two set-screws or a cotter. At the top part of the main levers, a little distance above the fulcrum, are two slide-links, W, which connect the levers to the cataract cylinder. The top ends of these levers are prolonged, and fitted with small rollers for working the tappets, O. The valve-moving and cataract cylinders are coupled together by two stays, X X.

The action of this valve gear is as follows:—

By the position of the valve, I, shown in the sectional elevation, fig. 105, steam will be admitted to the right-hand side of the valve-moving cylinder, Q, and thus move the main valve towards the left, and by that means admit steam into the main cylinder at the right-hand end, and consequently commence to move the main piston towards the left; but as soon as the

[1] P. R. Björling, *Direct-acting Pumping Engines*, pp. 84, 85; a Paper read before the Society of Engineers, May 7, 1877.

PLATE VI.

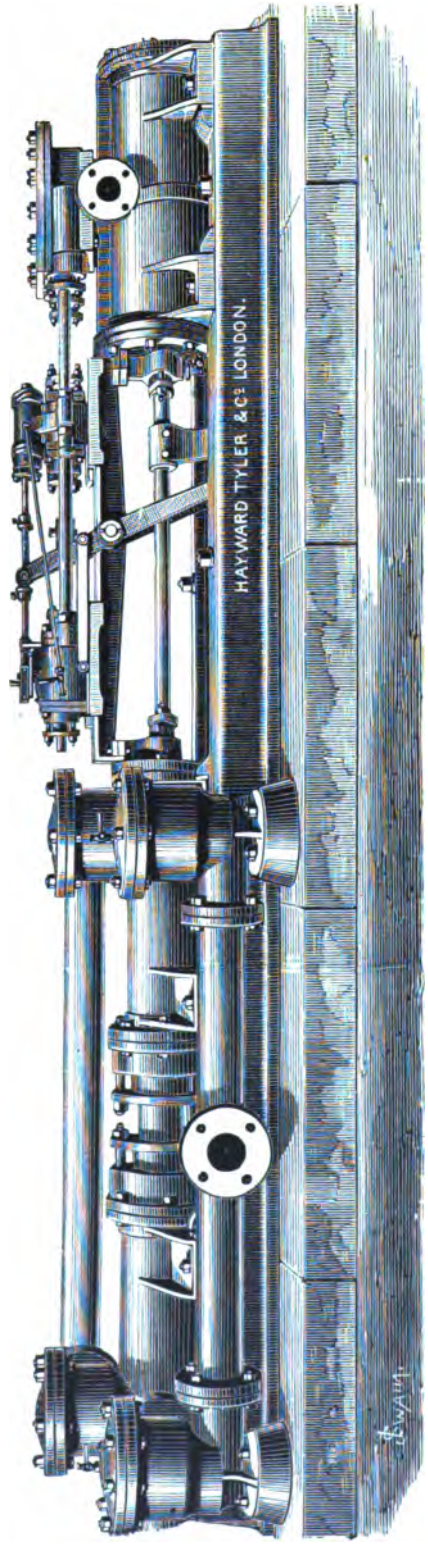


FIG. 104.—The 'Self-Governing' Plunger-Pump (Cope and Maxwell's Valve Gear)

[*To face p.* 150.

Valve-Ge
Transveri

piston commences to travel, the top part of the main levers, R, will also travel, but in the reverse direction (towards the right), and the valve-moving and cataract cylinders go with it; the slide-valve will still move onward to the left till the valve-moving piston, F, has come to the end of the valve-moving cylinder, Q, when the main valve will be taken back by the valve-moving cylinder, and cut off the steam. The rollers on the top of the main levers will strike the tappet, O, before the main piston has arrived at the end of its stroke, and thus by reversing the supplementary valve the whole is reversed. Now, suppose that the engine has commenced its stroke, and the resistance is very great, the main piston will travel on slowly, but the valve-moving piston will travel as fast as the cataract governor will allow; the main slide-valve will go to the end of its stroke before the main levers have time to pull the valve-moving and cataract cylinders back, thus cutting off the steam late; but if the load be light, the main piston will travel fast, and pull the valve-moving and cataract cylinders back, before the main valve has had time to travel to the end of its stroke, and therefore cut off the steam from the main piston early.

The water-pump is double-acting, consisting of two single-acting working-pumps or cylinders in a line with the main piston-rod, which is attached to a long hollow ram working through a stuffing-box at one end of each working-pump. There is an inlet-branch in the side of each cylinder near the outer end, to which is connected the suction valve chest (or nozzle). The delivery valve chest stands directly over the same end of each cylinder, and at right angles to the inlet-branch. The drawing represents metallic wing-valves in the delivery chest, with india-rubber springs for controlling the motion of the valve and giving it a quick return.

'When this engine was exhibited at the Royal Agricultural Society's Show at Birmingham, the delivery-pipe was throttled by means of a screw-down valve, until the resistance on the pump-ram was so great as to nearly balance the pressure of steam in the cylinder, of course materially reducing the speed of the piston. The delivery-pipe was suddenly opened by two sharp turns of the hand-wheel when the main piston had completed three-quarters of its stroke, without any appreciable augmentation in the speed of piston to which the cataract governor was adjusted. The author thinks this was a good proof of the sensitiveness of the self-governing gear. The slide-valve of this engine works in a similar manner to an eccentric-moved valve, opening and cutting off steam quickly, not, as is the case in most direct-acting automatic expansive engines, with a slow motion and "wire-drawing" the steam.'

'Another great advantage in this gear is the ease with which the valves are set; almost any ordinary engine-fitter can do it. . . . These engines can, of course, be made either high or low-pressure, compound or non-compound, according to the degree of economy of fuel required, the space which can be allotted to it, and other circumstances.'[1]

[1] P. R. Björling, *Direct-acting Pumping Engines*, pp. 86, 87.

Messrs. Hayward-Tyler & Co., of London, are the sole makers of this engine in this country.

The 'Davidson' Plunger-Pump.

This pump, represented in perspective elevation by fig. 108 (which is from a photograph of a 22 × 11 × 22-inch pump), is a very good example of Class

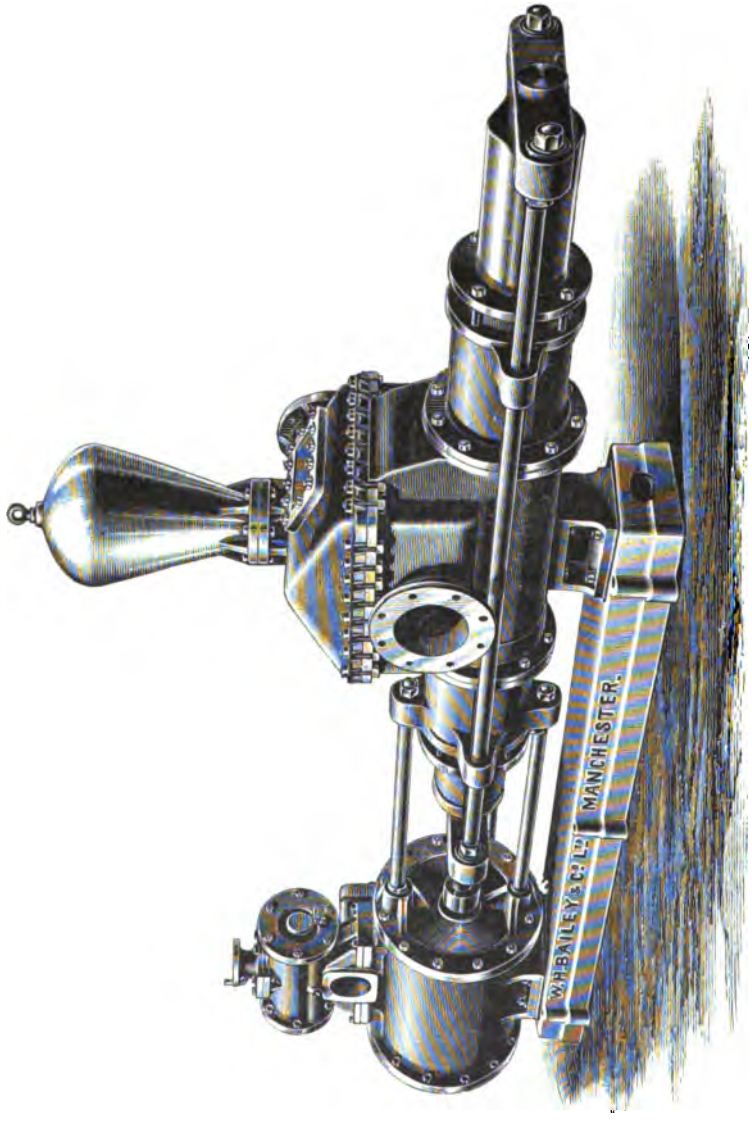


Fig. 108.—The 'Davidson' Plunger-Pump.

II *b* (outside-packed; two single-acting plungers). This type is suitable for lifts up to 300 feet. The plungers work into each end of a cylinder having a central partition, and deliver from their inside ends. There is a direct central connection with the piston-rod for the front plunger, and a crosshead and side rods making a side connection for the rear plunger. The outer end of each plunger works through a stuffing-box at the end of the water-chamber.

The plungers work in brass-bushed glands; the valves and valve-seats are of gun-metal.

The standard sizes, etc., are as follows:—

Dia. of steam cyl.	Dia. of plunger	Length of stroke	Approx. delivery at given speed		Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Approx. weight
			Strokes per min.	Water per hour					
in.	in.	in.		gall.	in.	in.	in.	in.	cwt.
5½	2¾	8	150	1,500	2	1½	¾	1	7
7	3½	10	120	2,450	2	1½	1	1¼	12
9	4½	12	100	4,000	2½	2	1	1½	20
10	4½	12	100	4,000	2½	2	1¼	2	23
10	5	12	100	5,000	3	2½	1¼	2	27
12	6	12	100	7,250	4	3	1½	2	33
14	7	14	86	9,950	5	4	2½	3	44
16	8	16	75	12,600	6	5	2½	3	60
18	9	18	67	16,200	7	6	2½	3	90
22	11	22	55	24,000	8	7	3½	4	144

The combinations enumerated will raise water about 240 feet with 40 lbs. of steam pressure.

For lifts up to 1,000 feet a stronger pump, with a cylindrical arrangement of water-chamber, is manufactured; the larger sizes have separate valve-boxes which can be readily detached from the pump.

The standard sizes, etc., of this type are as follows:—

Dia. of steam-cyl.	Dia. of plunger	Length of stroke	Approx. delivery at given speed		Height of lift with 40 lb. steam	Dia. of suction and delivery pipes	Dia. of steam pipe	Dia. of exhaust pipe
			Strokes per min.	Water per hour				
in.	in.	in.		gall.	ft.	in.	in.	in.
16	4	16	60	2,560	1,000	3	2½	3
16	5	16	60	4,000	600	3½	2½	3
18	6	18	54	5,750	400	4½	2½	3
16	6	18	54	5,750	520	4½	2½	3
22	6	24	40	5,750	820	4½	3½	4
22	7	24	40	7,900	500	5	3½	4
26	7	24	40	7,900	760	5	3½	4
26	8	24	40	10,250	550	6	3½	4
26	10	24	40	16,000	350	8	3½	4
30	8	24	40	10,250	730	6	4	5
30	10	24	40	16,000	470	8	4	5
36	10	24	40	16,000	670	8	5	6
36	12	24	40	23,000	470	9	5	6

For steam pressures above 50 lbs. per square inch this pump is made with compound cylinders; it is also made with triple-expansion cylinders for steam pressures up to 120 lbs. per square inch.

Messrs. W. H. Bailey & Co., Ltd., Salford, are the makers of this pump.

The 'Blake' Plunger-Pump.

This well-known American mining pump is shown in perspective elevation in fig. 109. The crossheads of the plungers are connected by substantial

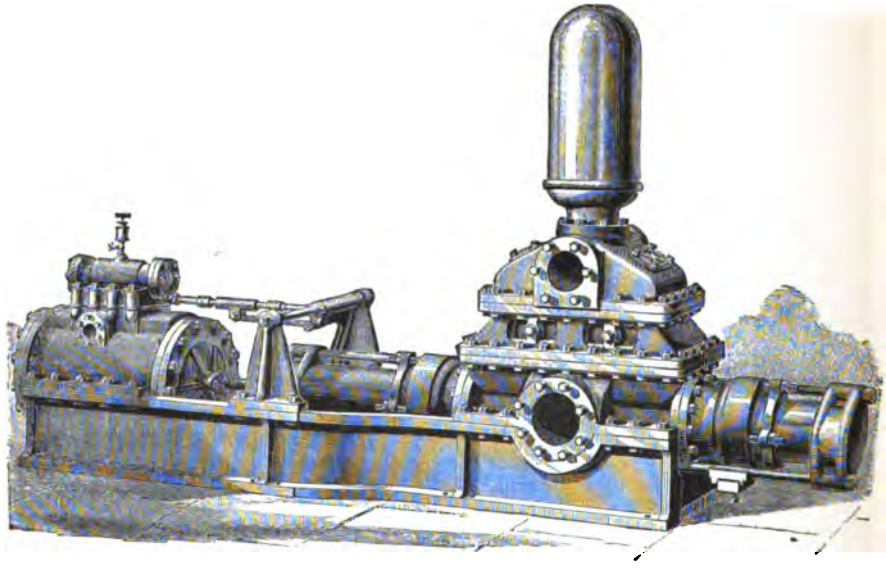


Fig. 109.—The 'Blake' Plunger-Pump.

rods of cold-rolled iron or steel, which are supported by and slide on adjustable ways or bearings, thus keeping the plungers in perfect line and preventing uneven wear.

All the working parts are accurately made from steel gauges, and are interchangeable. The plates that form the seats for the water-valves are made of heavy gun-metal composition, and can be readily removed in case of necessity; the valves are of the most approved form, and are made of the best quality rubber. The valve areas and water passages are exceedingly large, thus reducing water friction to a minimum, and insuring smooth working. This feature, together with an improved valve motion and perfect cushioning steam-cylinder, effects a pumping operation free from shock or jar.

The valve motion referred to being adjustable, a full stroke can be obtained at any speed and under any pressure when pumping; this conduces to economy in the use of steam, as the loss by clearance in the ends of the steam-cylinder is reduced to the lowest point.

The standard sizes are the same as those of the 'Knowles' pump.

This and the Knowles pump are made by the same company—the Blake & Knowles Steam-Pump Works, Ltd., London and New York.

The 'Knowles' Plunger-Pump.

This pump is made in three leading types to suit various duties, but all belonging to Class II *b*. The first of these is a low-lift pattern suitable for draining quarries or pumping water containing much gritty matter, under elevations not excessive. The small sizes are much used as boiler-feeders, especially where dirty water is used. In this type the water-cylinder and chest are cast in one piece.

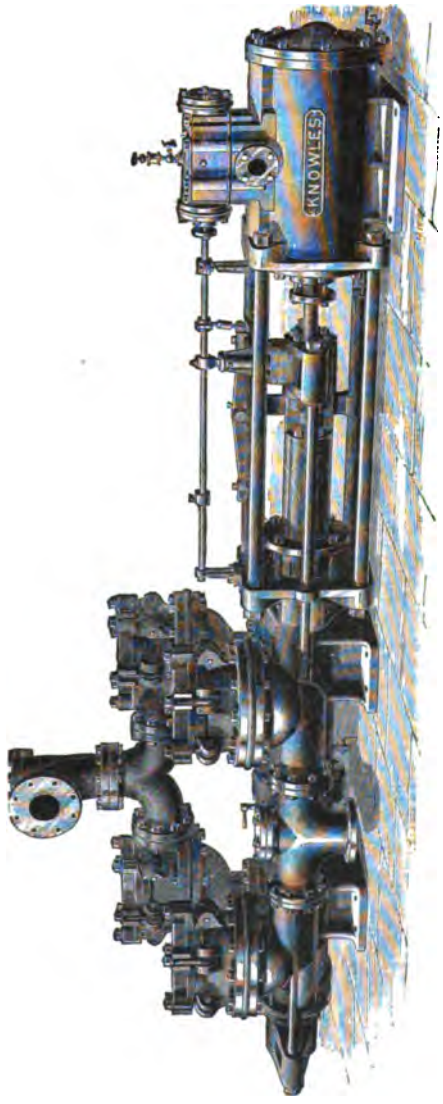


Fig. 110.—The 'Knowles' Plunger-Pump (Patent 'Pot-Valve' Pattern).

For heavy duty the Patent 'Solid-Cylinder' pattern is provided. The principle is the same as the above-named example, but the pump has a long stroke, and is designed for great strength in every part. The plunger alignment is very similar to that of the 'Blake' pump. The valves are of gun-metal composition faced with leather, and work on seats of the same alloy.

It is claimed that this improved form of pump, which is original with the makers, has many advantages not found in other forms of plunger-pumps. The heavy castings, absence of joints, and peculiar arrangement of valves and plungers, render this pump exceedingly durable; practically the only wearing part in the entire water-end, besides the valves, is the packing in the stuffing-boxes.

This form is suitable for lifts up to 1,000 feet.

The type known as the 'Pot-Valve' Plunger-Pump, of which fig. 110 is an elevation in perspective, is also well adapted for heavy mining work. It differs from the pump last described only in the arrangement of the water valves, which (as the illustration shows) are enclosed in heavy 'pots.' These valves are of special design, which has been patented, and possess the double advantage of quiet action and great durability. They work on independent gun-metal composition seats, and both valves and seats can be readily taken out in one movement after the covers of the 'pots' have been removed.

Dia. of steam cyl.	Dia. of plunger	Length of stroke	Water per stroke	Delivery at given speed		Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Floor space required	Approx. weight
				Strokes per min.	Water per hour						
in.	in.	in.	gall.		gall.	in.	in.	in.	in.	in.	cwt.
4	2½	5	·11	150	990	1¼	1	½	¾	63 × 12	4
5½	3¼	7	·25	125	1,875	2	1½	¾	1	74 × 14	6
6	3¾	7	·33	125	2,475	2	1½	¾	1	74 × 14	6
7½	4½	10	·69	100	4,140	3	2½	1	1¼	91 × 21	11½
8	5	10	·85	100	5,100	3	2½	1	1¼	91 × 21	11½
10	5	12	·85	100	5,100	5	5	1¼	1½	118 × 21	22½
12	6	12	1·47	100	8,820	5	5	2	2½	117 × 32	23
14	6	12	1·47	100	8,820	6	5	2	2½	117 × 32	24½
14	7	12	2·00	100	12,000	7	6	2	2½	118 × 34	28½
14	7	16	2·66	75	11,970	7	7	2½	3	156 × 35	46
16	7	12	2·00	100	12,000	7	6	2	2½	118 × 34	31½
16	8	12	2·61	100	15,660	7	6	2	2½	117 × 28	38¼
18	10	16	5·44	75	24,480	8	6	2½	3	142 × 32	58

Dia. of steam cyl.	Dia of plunger	Length of stroke	Water per stroke	Delivery at given speed		Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe
				Strokes per min.	Water per hour				
in.	in.	in.	gall.		gall.	in.	in.	in.	in.
16	7	24	4·00	50	12,000	7	6	2½	3
16	8	16	3·48	75	15,660	8	6	2½	3
16	8	24	5·22	50	15,660	8	6	2½	3
16	9	16	4·44	75	19,980	9	8	2½	3
16	9	24	6·60	50	19,800	9	8	2½	3
16	10	24	8·16	50	24,480	10	8	2½	3
18	8	16	3·48	75	15,660	8	6	2½	3
18	8	24	5·22	50	15,660	8	6	3½	4
18	9	16	4·44	75	19,980	9	8	2½	3
18	9	24	6·60	50	19,800	9	8	3½	4
18	10	24	8·16	45	22,032	10	8	3½	4
20	8	24	5·22	50	15,660	8	6	3½	4
20	9	24	6·60	50	19,800	9	8	3½	4
20	9	36	9·92	34	20,236	9	8	3½	4
20	10	24	8·16	45	22,032	10	8	3½	4
20	10	36	12·24	30	22,032	10	8	3½	4
24	9	24	6·60	50	19,800	9	8	4	4½
24	9	36	9·92	34	20,236	9	8	4	4½
24	10	24	8·16	45	22,032	10	8	4	4½

Dia. of steam cyl.	Dia. of plunger	Length of stroke	Water per stroke	Delivery at given speed		Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe
				Strokes per min.	Water per hour				
in.	in.	in.	gall.		gall.	in.	in.	in.	in.
24	10	36	12·24	30	22,032	10	8	4	4½
24	12	24	11·75	45	31,725	10	8	4	4½
24	12	36	17·63	30	31,734	12	10	4	4½
24	14	24	16·00	45	43,200	12	10	4	4½
24	14	36	24·00	30	43,200	12	10	4	4½
24	16	24	20·88	45	56,376	14	12	4	4½
24	16	36	31·32	30	56,376	14	12	4	4½
28	10	24	8·16	45	22,032	10	8	5	6
28	10	36	12·24	30	22,032	10	8	5	6
28	12	24	11·75	45	31,725	10	8	5	6
28	12	36	17·63	30	31,734	12	10	5	6
28	14	24	16·00	45	43,200	12	10	5	6
28	14	36	24·00	30	43,200	12	10	5	6
28	16	24	20·88	45	56,376	14	12	5	6
28	16	36	31·32	30	56,376	14	12	5	6
30	10	24	8·16	45	22,032	10	8	5	6
30	10	36	12·24	30	22,032	10	8	5	6
30	12	24	11·75	45	31,725	10	8	5	6
30	12	36	17·63	30	31,734	12	10	5	6
30	14	24	16·00	45	43,200	12	10	5	6
30	14	36	24·00	30	43,200	12	10	5	6
30	16	24	20·88	45	56,376	14	12	5	6
30	16	36	31·32	30	56,376	14	12	5	6
30	18	24	26·44	45	71,388	16	14	5	6
30	18	36	39·66	30	71,388	16	14	5	6

Where the duty is very arduous and the water is strongly impregnated with acid, these pumps are constructed of the hardest iron it is possible to work, the metal being made from two to three inches thick, and all water passages equal in area to the plungers.

The makers claim that in economy of steam consumption this pump is superior to any direct-acting pump not having compound steam-cylinders.

The foregoing tables give details of sizes, capacity, etc., of pumps for various duties. The first group are pumps for low lifts and light duties; the second and third groups are pumps for high lifts and heavy duties in mines.

The 'Special' Plunger-Pump.

This is yet another example of the 'outside-packed' pump (Class II *b*), and is shown in fig. 111, which is from a drawing of the 21 × 6 × 24 inches size. In this type, which is supplied without an air-pump condenser or (as in the specimen given) with one, the pumps are strong enough for lifts not exceeding 1,000 feet, and for a maximum steam pressure of 100 lbs. per square inch. Users of this as of all other pumps should not exceed the maker's specified limit of steam pressure and 'head.'

The valves are of brass and of the multiple type, and carried in separate valve-boxes bolted to the pump body. The suction inlet is at the front; the delivery outlet can be turned back or front. The air-vessel is arranged to bolt to the floor at any convenient position near the pump, to which it is connected by piping.

When an air-pump condenser is supplied it is mounted on the base-plate at the back of the steam-cylinder, and has a brass-lined barrel, brass bucket, valve-seats, and guards, india-rubber valves, brass spray pipe, injection valve, vacuum gauge, and connecting pipes to the steam-cylinder.

The following are the standard sizes and dimensions:

Dia. of steam cyl.	Dia. of plunger	Length of stroke	Approx. delivery per hour	Dia. of suction and delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Approx. width over all without air-vessel	Approx. height without air-vessel	Approx. length over all	
									Without condenser	With condenser
in.	in	in.	gall.	in.	in.	in.	in.	in.	in.	in.
16	5	24	4,000	3½	3	3½	42	55	204	273
18	5	24	4,000	3½	3½	4	42	55	204	273
18	6	24	5,760	4	3½	4	42	55	204	273
21	6	24	5,760	4	4	5	45	60	205	274
21	7	24	7,840	5	4	5	45	60	205	274
24	7	24	7,840	5	4½	5½	49	69	208	289
24	8	24	10,240	6	4½	5½	52	69	208	289
26	8	24	10,240	6	5	6	56	74	210	291

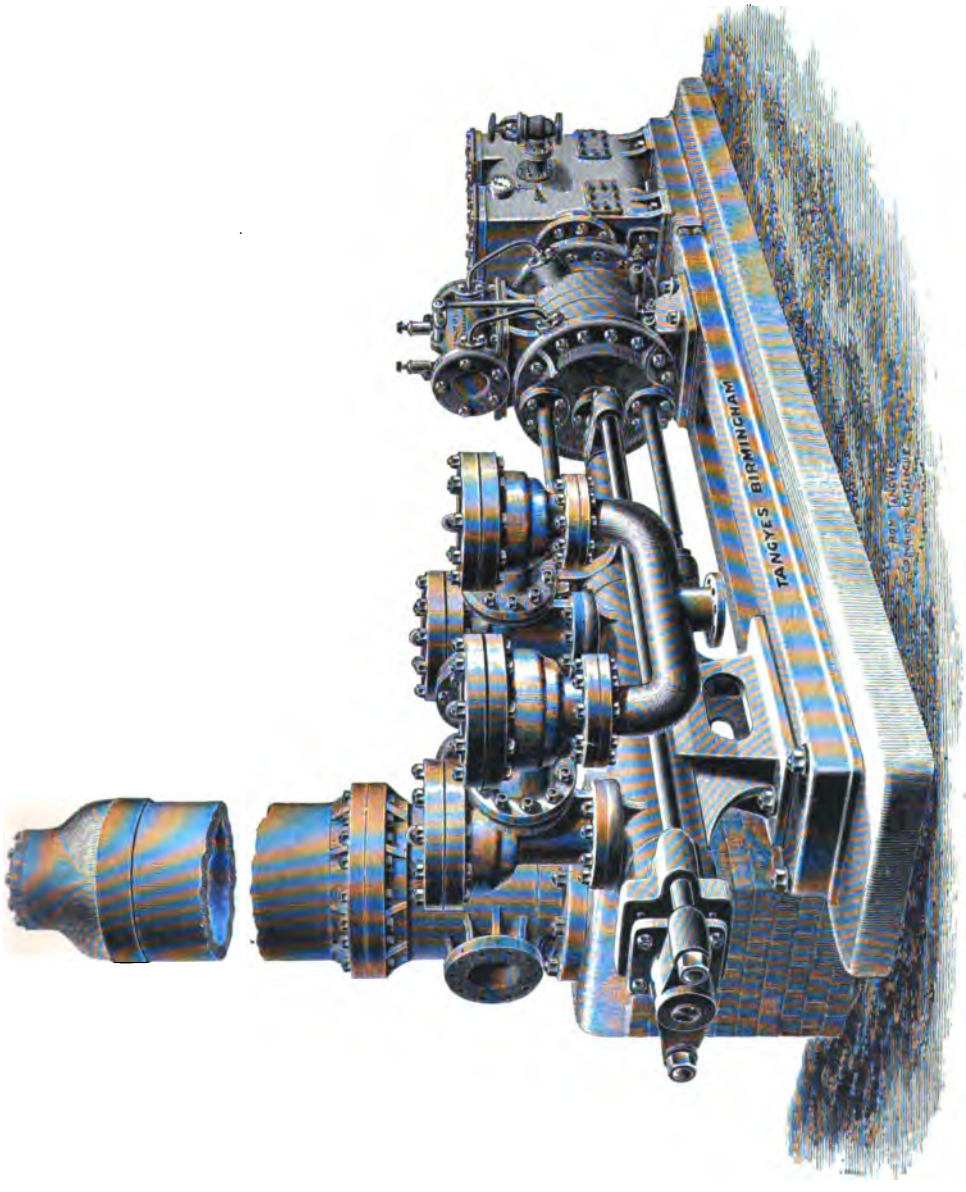


FIG. 111.—The 'Special' Plunger-Pump—1,000 ft. Double-Ram Type (with Air-Pump Condenser).

[*To face p.* 158.

3.—TWO STEAM-CYLINDER, NON-EXPANSIVE, NON-CONDENSING ENGINES WORKING DOUBLE-ACTING PISTON-PUMPS.

'Duplex' Pumps.

In our historical notes necessary considerations of space and proportion precluded other than a brief reference to the invention and introduction of the 'Duplex' Engine. The subject is one of such deep interest and importance, marking, indeed, an epoch in the history of direct-acting engines, that we should be wanting in justice both to the inventor and the invention not to consider with some closeness of thought and elaboration of treatment the origin and development of a machine that with some modifications has been imitated in every great pump-engineering works of the world.

The inventor's notes enable us to some little extent to trace the processes of thought and the course of reasoning, and to follow the various stages of investigation by which Worthington travelled to this his final goal, and the consummation of his splendid career, and we may both pleasure and profit ourselves and honour his memory by pausing for a review and a study of the circumstances of the evolution of the 'Duplex' engine.

It is worthy of remark that in none of Worthington's inventions were the requirements of mining present to his mind; his first pump was designed to meet the exigencies of canal navigation, and successive improvements were made in connection with engines for river steamboats, and new designs of water-valves were introduced in the same association, whilst the requirements of waterworks called into existence some notable types of engines, as we shall presently see, to which the system of compound cylinders, which some years before had come into use, was applied. It was for the same service that the 'Duplex' engine was designed and introduced.

After speaking of pump-valves designed by him for the steamer 'Washington' in 1850, Worthington says: 'I come next to a point in my experience of some importance, involving new considerations and justifying much greater cost and complication of engineering than any hitherto called for in my business. I refer to the department of waterworks for cities and towns. My first connection with any important enterprise of this kind was at the city of Savannah, where the second compound condensing engine, under the patent of Worthington and Baker

was erected in the year 1854. . . . The valve is thrown by relief motion, and the compound cylinders are annular in their arrangement. A single slide-valve performs the somewhat complicated function of giving steam to the high-pressure piston, and of making a communication with the expanding piston on the one side, and with the condenser on the other. This valve is balanced, or rather the superincumbent pressure upon it is reduced by a piston, working in a small cylinder upon its back, and attached by a suspension bar to a permanent point in the dome of the steam-chest . . . this arrangement does not balance the valve in any proper sense of the term, but only suspends as much weight as is received on the area of the piston, which swings back and forth as the valve travels. All the weight thus suspended costs but little in the way of friction, as the motion at the point of support is scarcely appreciable. I patented this manner of relieving the valve of pressure in 1856, and have used it ever since upon all my large engines.'[1] This engine was fitted with an air-pump surface-condenser, and Worthington says that the efficiency of the engine was due, in no inconsiderable part, to the efficiency of its condensing apparatus.[2]

'A duplicate of the Savannah engine was erected at Cambridge, Mass., in the year 1856. Its dimensions were: high-pressure cylinder, 12 inches diameter; low-pressure cylinder, 25 inches diameter; plunger, 14 inches diameter; length of stroke, 25 inches. Its contract guarantee was to deliver 300,000 gallons in 24 hours, one hundred feet high.'[3] This engine and other engines (Cornish at Jersey City and Philadelphia, Rotative at Brooklyn, and Crank engine at Hartford) were subjected to exhaustive trials at various dates between June 1856 and January 1860, the Worthington engine attaining the highest duty.[4]

Admirable as was the Cambridge engine, Worthington was not satisfied with it. The action of the pump, in common with all pumps of its class, was an intermittent one, the water set in motion at the beginning of the stroke coming to a dead stand at its termination;[5] thus the flow of the water was irregular, and the pump and its connecting pipes and joints were subjected to severe and sometimes serious strains and concussions. To use Worthington's own words: 'It soon became evident to my mind, that the small engine at Cambridge, economical in the use of coal, and durable as it proved itself, was fully as large as it was desirable to build an engine of its character. The sudden reciprocation produced a jar and recoil which, while comparatively insignificant on this small engine, threatened to be distressing

[1] Henry R. Worthington, *The Worthington Pumping Engine*, pp. 16 and 19.

[2] *Ibid.*, p. 22. [3] *Ibid.*, p. 23.

[4] This engine was subjected to two tests, one in April and the other in June 1857. The duty, after deducting 5 per cent. for loss in pumps, etc., was 66,941,100 and 67,574,600 lbs. respectively.

[5] An air-vessel in a case of this kind would keep the water in the delivery main in motion even after the pump had come to a stand.—S.M.

if not destructive upon a larger one.'[1] The problem that faced Worthington was not so simple as at the first glance it seemed, as it involved opposing conditions neither of which, apparently, could be satisfied without sacrificing the other; in short, to induce inertia, and yet maintain momentum in the delivery main. To secure immunity from strains and stresses by giving the engine a sufficient pause at the end of each stroke for the valves to close would be easy of accomplishment, but it would lead to a serious loss of efficiency by making the discharge through the delivery main an intermittent instead of a continuous one. Worthington laboured at this problem and solved it between the years 1857 and 1860 by the invention of the 'Duplex' pump. And when, as the result of the duty trials named, the Water Commissioners of Brooklyn decided to nominate the Cambridge engine[2] as the one to take the place of the Cornish engine called for in the contract, Worthington submitted his Duplex engine (a modification of the Cambridge engine), which he was then perfecting and endeavouring to introduce into important works. The Commissioners agreed, but a hitch occurred with the contractor, who, it appears, made unreasonable and absurd demands in regard to time and fulfilment. 'Compelled to relinquish this desirable opportunity to place the engine in an important and conspicuous location, I waited for the next one, which occurred at Charlestown, Mass., in the year 1863. The engine was there adopted under full guarantee of performance, at least equal to that of any engine in the United States, under penalty of removal in one year in the event of failure. It succeeded, and was followed by another of five millions capacity in 1867, and by still another of eight millions capacity in 1872.[3]

The following extracts from Report on Hydraulic Exhibits at the International Exhibition, Philadelphia (1876), by Mr. Charles E. Emery, Consulting Engineer, New York, one of the Judges of Group 20, afford a good description of the Duplex engine as used for waterworks, and lucidly explain the method of operation of the valve gear, which is the most distinguished feature of the engine:—

'The largest and most expensive exhibit was the pumping engine for supplying the entire Exhibition grounds with water, which was furnished by Mr. Henry R. Worthington, of New York, and was located on the west side of the Schuylkill, just outside the enclosure, the stand-pipe, 120 feet high, and 208 feet above the river, being within the grounds near the Art Gallery. The engine was of the Worthington Duplex type, with a capacity of six million gallons daily. . . . There are two horizontal double-acting pumps with plungers 22¼ inches in diameter, arranged side by side on the same frame, each operated directly by a compound engine with steam-jacketed cylinders, 29 and 50¼ inches in diameter, the strokes of engines and pumps being four feet. The smaller steam-cylinder is attached

[1] Henry R. Worthington: *The Worthington Pumping Engine*, p. 24.
[2] The reader will remember that this was a compound condensing engine.—S. M.
[3] *Op. cit.*

to the front head of the larger, and has a central piston-rod connecting with pump-rod through a crosshead, and two piston-rods from larger cylinder pass outside the smaller, and connect with the crosshead. There are two single-acting air-pumps each 29¾ inches in diameter, with 24-inches stroke, which are operated from the ends of a horizontal beam, with vertical lever attached, receiving motion from one main crosshead. The main valves are plain slides operating over double cylinder ports, as described hereafter.'

'The valves for both cylinders of each engine are arranged on the same stem by raising the chest of the smaller, and each valve is provided with a balancing piston. The valves of one engine are operated by bell cranks directly under from the reciprocating parts of the other, and no rotative movements, with accompanying details, are required. As previously stated, double cylinder ports are provided. The outer ones receive steam past the ends of the valves, and admit the same to the cylinder in the usual way. The inner ones communicate with the exhaustive cavity of the valve only, and enter the cylinder at such distances from the ends that when steam is exhausting through one of the ports, the main piston will run over and close it, and cushion upon the vapor thereby inclosed, the outer port being at the time shut off by the main valve. Valves are provided to put the two cylinder ports at each end in communication to regulate the extent of cushioning. The pump valves consist of rubber disks arranged in chambers above and below the plungers. Each plunger runs without packing in a long grooved ring in a central diaphragm.'

The *modus operandi* is thus described: 'In operation, one engine, while in full action, moves the valves of the other, when the pistons of the latter gradually begin to move and finally attain full velocity, as those of the first are checked by the steam cushions, and gradually come to rest, the pump valves meantime seating quietly.'

'The first engine pauses a moment till the second engine admits steam, when it commences a return stroke, and the second comes to rest, the action of one blending into that of the other as each alternately takes up the load, the result being that the discharge is uniform; a uniform pressure is maintained in the main, and the pumps under heavy or light pressure operate without jar or noise.'[1]

If imitation be the sincerest and the most reliable verdict of judges and critics, then the importance and the practical utility of Worthington's invention are universally acknowledged, for his engine has been universally copied. The first Duplex pumps made in this country appear to have been modelled very closely on the American prototype, but before very long English engineers saw directions in which some modifications could be introduced with advantage, making it more conformable to English ideas and requirements. But these innovations did not affect the essential

[1] Henry R. Worthington: *The Worthington Pumping Engine*, p. 45.

features of the pump which, all the world over, continues to bear the impress of Worthington's genius.

Compared with the more elementary form, the Duplex pump has several advantages for general purposes, and for mining use at surface. We say *at surface* advisedly for reasons that will be considered presently. There is greater regularity and certainty of action, the steam-valve gear being operated with as much certainty as that driven by a crank and eccentric. It will start from any position immediately steam is turned on, and it does not stop in an arbitrary manner. There is no dead point, no overrunning the stroke, nor making short ones, and no possibility of the engine 'running away,' the interdependence and co-operation of gears securing a perfectly regular and uniform motion.

The combined discharge of the two cylinders is practically continuous; this secures immunity from shocks and jars, and greatly reduces the risk of leaky joints in the column pipe, and admits of the pipe being made smaller, and consequently lessens the outlay therefor.

We have no data of 'duty,' and can only assume from its construction and the method of its action that it has an advantage over the single-cylinder engine in this respect. We should expect a 20-inch Duplex pump, for example, to get through more than double the work of a 20-inch single-cylinder pump with not more than double the quantity of steam. Or, to put it another way, that a 20-inch Duplex engine will pump more water on the same steam expenditure than a 28¼-inch single-cylinder engine which has practically the same cylinder capacity.

Having more external moving parts and more complicated mechanism than its single-cylinder congener, the Duplex pump is not so well adapted for sinking operations or for any underground use where the water is bad and carries grit, and the pump is exposed to dust and dirt and blows from fragments of rock.

One authority says: 'The Duplex pump may be used under many circumstances, and for many purposes. It may be admitted, however, that it requires rather more attention, . . . and that the outside valve gear and greater number of moving parts do not fit the Duplex so well for situations where wet, dirt, dust, and neglect are apt to prevail. A small Duplex pump is, for example, too refined to be placed in a mine shaft, a quarry, or a dip working, unless it is thoroughly protected from dirt or accident, and better attended to than is usual in such situations.'[1]

In the article on single-cylinder engines we have already sufficiently described the water-ends of piston and plunger-pumps; it will, therefore, not be necessary to enter upon any explanation of the hydraulic parts of 'Duplex' pumps, which are similar to those of the single-cylinder engines, save that they are duplicated. What little descriptive matter may be given

[1] D. H. Morton, A.M.I.C.E., M.I.M.E.: *Notes on Steam Engines, Pumps, etc.*, p. 130.

in addition to that already supplied will, consequently, be confined to the steam-end of these pumps.

In situations where it can be taken good care of, where the water is clean, and where it can be shielded from the evils named, the Duplex pump answers very well, and is a most effective machine. We may note in passing that the medium and small sizes are very popular for boiler-feeding and for general donkey-engine purposes, being very extensively used for this and other purposes in the navy, in factories, etc., the many good qualities enumerated on the preceding page admirably adapting the Duplex pump for such uses.

As we have remarked in the case of the single-cylinder pumps, so here, the plunger-pump is better adapted for underground use than the piston-pump, which can only be recommended for pumping perfectly clean, non-acidulous water, free from grit and other solid matter.

The Worthington Piston-Pump.

The name 'Duplex' was given to this construction early in the history of the invention, and it has ever since been commonly known by that name, as are all the imitations of it in this and other English-speaking countries. The makers, writing in 1887, say: 'As this designation has recently been adopted for pumping machinery of various kinds, we have been compelled to abandon it. The machines will therefore be called the "Worthington Pumping Engine," or "Worthington Steam-Pump" in our circulars and other publications.'[1] Whenever, therefore, we speak of a 'Worthington' engine, it must be understood that an engine of the 'Duplex' type is referred to, either of the simple class (which we are now considering) or of the compound or triple-expansion class.

Primarily designed for waterworks, for which it has been most extensively adopted and with the greatest success, the Worthington engine, whilst retaining the essential features of the waterworks engine, has been adapted to the very different service of underground pumping, a service which does not afford anything approaching the same scope and opportunity for the achievement of great results.

It does not appear that the Worthington pump has yet found its way in any considerable numbers into English mines and collieries, but in the United States, where less consideration is given to permanence and economy of service than in this country, the dominating factors being cheapness of first cost and quickness of installation, this pump, in common with other types of steam-pumps, is largely used.

It has been elsewhere stated that the valve motion is the prominent and distinguishing peculiarity of the Worthington pump. To this it owes its complete exemption from noise or concussive action. Two steam-pumps are placed side by side, and so combined as to act reciprocally upon

[1] *The Worthington Pumping Engine*, p. 54.

the steam-valves of each other. The one piston acts to give steam to the other, after which it finishes its own stroke, and waits for its valve to be acted upon before it can renew its motion. This pause allows all the water-valves to seat quietly, and removes everything like harshness of motion. As one or the other of the steam-valves must be always open, there can be no dead point. The pump is, therefore, always ready to start when the steam is admitted, and is managed by the simple opening and shutting of the throttle-valve.

Special care has been taken to have the parts easily accessible for

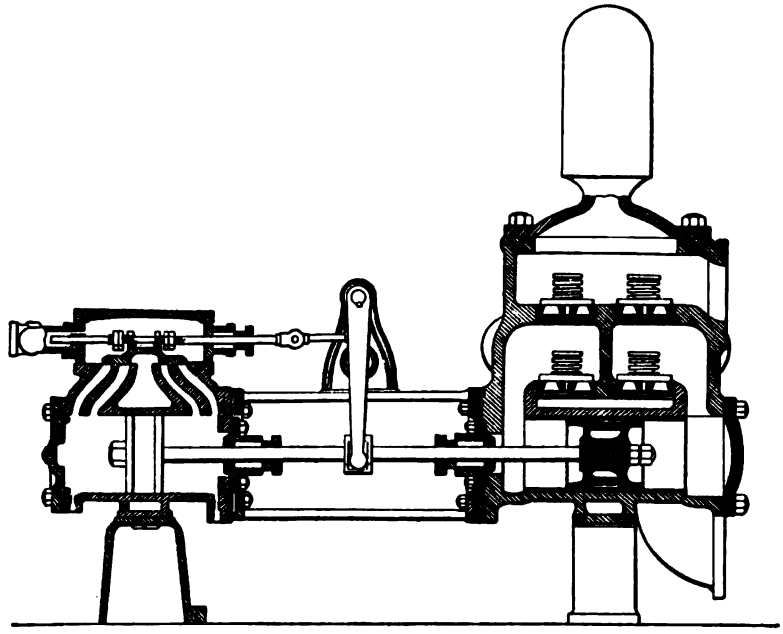


FIG. 112.—The Worthington Piston-Pump (General Service Pattern); longitudinal section.

inspection or repairs. All the moving pieces, being made to gauge, can be readily renewed.

As now made, all the valve-motion parts, including the spool on the piston-rod, are steel; all circular parts are made from rolled-steel rods, and other irregular parts drop-forged. All the wearing surfaces of the valve-motion are amply large, and all pins are hardened.

On the large sizes of pumps the piston-rods are divided at the spool, which enables the steam and the water piston-rods to be drawn at their respective ends, therefore requiring less space for drawing these rods than in the case of solid ones. Although this construction is more expensive, it has been found in many cases to be advantageous, especially where

pumps are used on shipboard, electric light stations, and other services where the space is limited. In addition to the advantage of space, it allows the steam-end of the piston-rod to be always made of steel, whereas the water-end of the rod can be made of bronze or other suitable metal for pumping salt or acid water.

Figs. 112 and 113 are sectional views of one side or half of two types of Worthington Piston Pumps, and exhibit the great simplicity of its interior arrangement, especially that pertaining to the steam-valve, which, as may be seen at E (fig. 113), is an ordinary slide-valve working upon a flat face over ports or openings. The motion of this valve is produced by a vibrating arm, seen at F, which swings through the whole length of the stroke, with long and easy leverage. It is claimed that as the moving parts

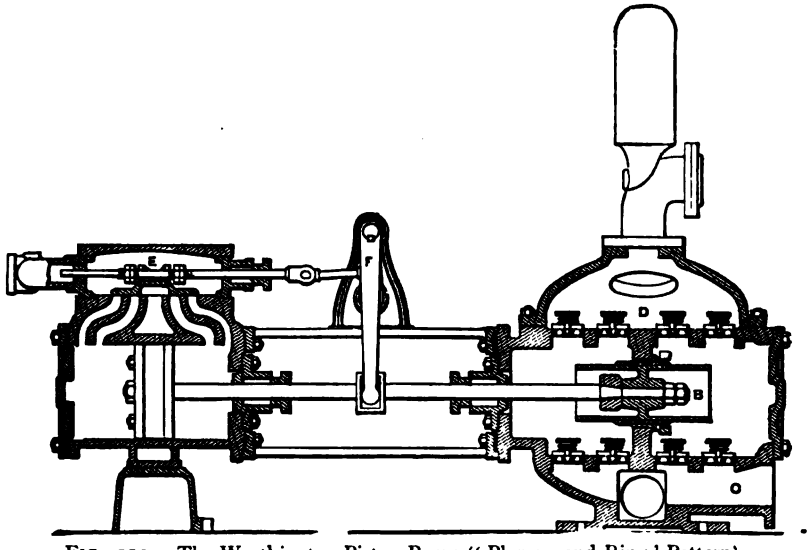


FIG. 113.—The Worthington Piston-Pump ('Plunger and Ring' Pattern); longitudinal section.

are always in contact, the blow inseparable from the tappet system is avoided, and that even the motion of the well-known eccentric upon crank engines is not comparable to this for moderate friction and durability.

The piston, or as the makers call it, double-acting plunger, shown at B, works through a deep metallic packing-ring, bored to an accurate fit, being neither elastic nor adjustable. Both the ring and the piston can be quickly taken out, and either refitted or exchanged for new ones at small cost; and if it be desired at any time to change the proportions between the steam-pistons and pumps, a piston of somewhat larger size, or decreased to any smaller diameter, can be readily substituted. As exact proportions between the power and work are always desirable, if not necessary, this is a very important advantage.

This system of renewal of the working parts has been proved by long experience to be the least expensive and most satisfactory for ordinary work. The piston is located some inches above the suction-valves, to form a subsiding chamber, into which any foreign substance may fall below the

FIG. 114.—The 'Worthington Patent Independent Jet Condenser;' longitudinal elevation.

wearing surfaces. This enables it to work longer without renewal than the usual form of piston-pump, especially in water containing grit or other solid material. The water enters the pump from the suction chamber C, through the suction-valves, then passes partly around and partly by the end of the

plunger, through the delivery valves, nearly in a straight course, into the delivery chamber, D, thus traversing a very direct and ample water-way. The bottom and top plates furnish a large area for the accommodation of the valves. These consist of several small discs of rubber or other suitable material, easy to examine and inexpensive to replace.

Fig. 112 is termed by the makers a 'Piston Pump' for general service, and fig. 113 the 'Plunger and Ring' pattern, although they are both virtually piston-pumps.

Fig. 114 is a longitudinal elevation of the 'Worthington Patent Independent Jet Condenser,' by the application of which to non-

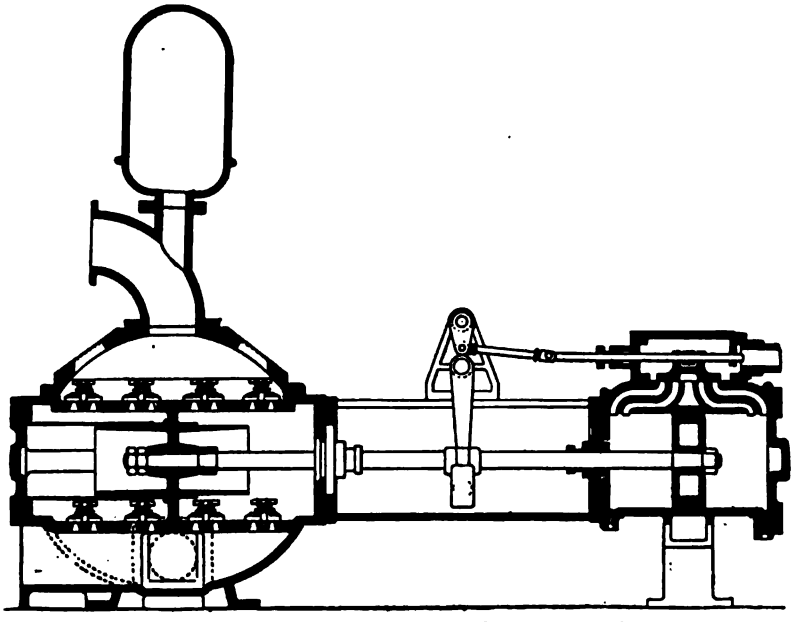


FIG. 115.—The 'Northey' Duplex Piston-Pump; longitudinal section.

condensing engines the makers claim that 25 per cent. saving in the steam consumption, and hence in the fuel burned, is frequently obtained.

Fig. 115 is a longitudinal section of the 'Northey' Duplex Piston-Pump, and fig. 116 a longitudinal elevation of 'Shanks's Duplex Piston-Pump.'

The latter is made in the following standard sizes, but of course any combination that may be required can be made. Sizes below 12-inch steam-cylinders are omitted; the strokes of each piston vary from 75 to 125 per minute, according to the kind of work and pressure. The stroke for the sizes given is 10 inches.

Dia. of steam cylinders	Dia. of water cylinders	Water per stroke of each piston	Water per hour by both pistons	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe
in.	in.	gall.	gall.	in.	in.	in.	in.
12	5¼	·77	6,930 to 11,550	6	5	2½	3
12	6	1·01	9,090 ,, 15,150	6	5	2½	3
12	7	1·38	12,420 ,, 20,700	6	6	2½	3
12	7½	1·60	14,400 ,, 24,000	6	6	2½	3
12	8½	2·04	18,360 ,, 30,600	6	6	2½	3
14	6	1·01	9,090 ,, 15,150	6	5	2½	3
14	7	1·38	12,420 ,, 20,700	6	6	2½	3
14	7½	1·60	14,400 ,, 24,000	6	6	2½	3
14	8½	2·04	18,360 ,, 30,600	6	6	2½	3
14	9¼	2·42	21,780 ,, 36,300	6	7	2½	3
16	7½	1·60	14,400 ,, 24,000	6	6	2½	3
16	8	1·81	16,290 ,, 27,150	6	6	2½	3
16	8½	2·04	18,360 ,, 30,600	6	6	2½	3
16	9¼	2·42	21,780 ,, 36,300	6	7	2½	3
18½	8½	2·04	18,360 ,, 30,600	6	6	3	3½
18½	9¼	2·42	21,780 ,, 36,300	6	7	3	3½
20	8½	2·04	18,360 ,, 30,600	6	6	4	5
20	9¼	2·42	21,780 ,, 36,300	6	7	4	5

TANGYES' DUPLEX PISTON-PUMP.

At fig. 117 is shown a longitudinal section of this pump, of the 300-feet series. The manufacturers make the following observations: 'This pump has been designed to retain the principle of the Duplex pump, its freedom from shock, easy working, etc. Its principal advantages are as follows:— The pump will make full strokes under all ordinary working conditions, and the great loss of steam, due to the large amount of clearance in the steam-cylinders when a pump is making short strokes, is avoided. The valve gear is simple and strong, and being free from all small pins, etc., is not liable to derangement or breakage. The crossheads are guided in the distance-pieces, thus preventing twisting and bending of the rods. The pump valves are easily accessible, and can be examined, cleaned, or taken out without moving the pump or breaking the joints of the suction and delivery pipes; the valve seats are tapered and fitted with central spindles secured to the pump body, thus avoiding the trouble and annoyance due to the beat of the valve, loosening and finally knocking out the seat, which is inevitable with all screwed or other types of valves having spindles fixed to the seats instead of to the pump casting.'

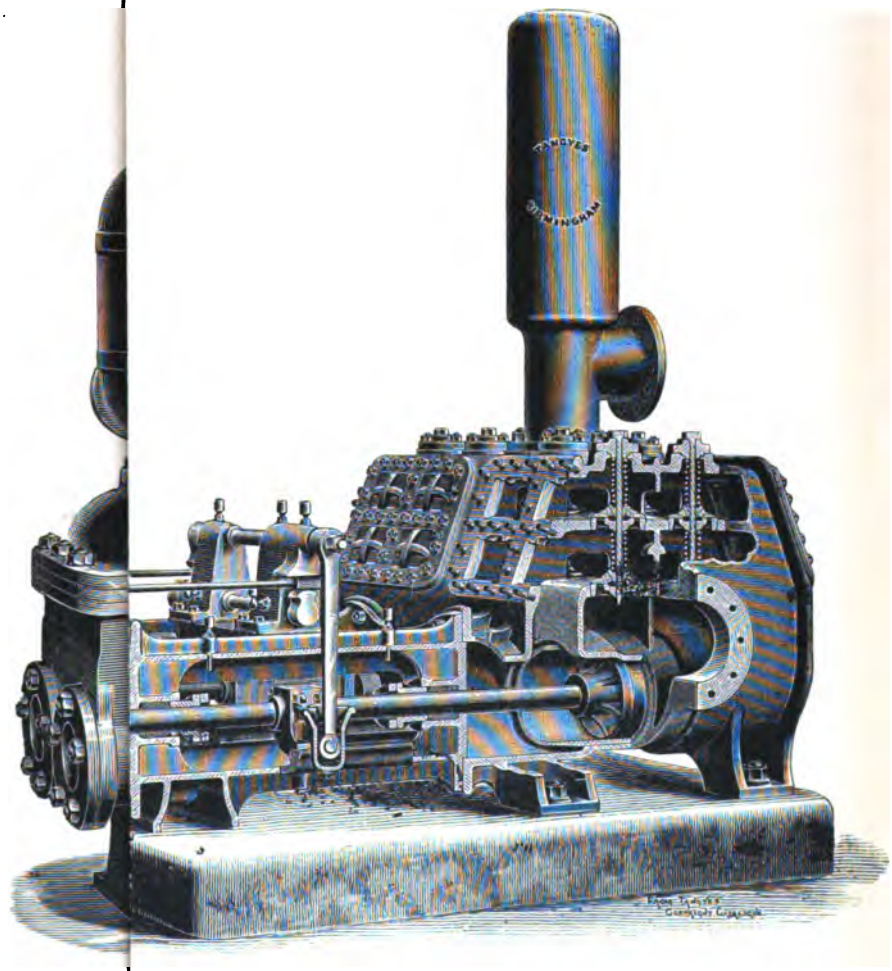
'The pump barrels are fitted with long gun-metal liners, and being below the suction valves always remain charged. The buckets have leather or other packings, and do not permit the excessive leakage which is found in all non-adjustable plungers after they have been at work for a short time.'

'The pump has two suction inlets, so that the suction pipe can be connected to either side; it has very low centres, and the distance-pieces being cast together, the whole is very rigid, and all distortion or twisting when at work is prevented.'

The pump is made in a copious gradation of sizes from 5 × 4 × 12, with an hourly capacity of 4,800 gallons to 18 × 14 × 12, with an hourly capacity of 58,800 gallons; the following are the standard sizes above 13-inch steam cylinders. The length of the stroke of each pump is 12 inches.

Dia. of steam cyl.	Dia. of water cyl.	Water per hour (approx.)	Dia. of suction pipe	Dia. of deliv. pipe	Dia. of steam pipe	Dia. of exh'st. pipe	Length and width	Height to top of air vessel	Approximate weight
in.	in.	gall.	in.	in.	in.	in.	in.	in.	cwts.
14	6	10,800	6	5	2½	3	103 × 39	76	53
14	7	14,700	6	5	2½	3	103 × 39	76	53
14	8	19,200	8	7	2½	3	108 × 52	89	72
14	9	24,300	8	7	2½	3	108 × 52	89	72
14	10	30,000	9	8	2½	3	112 × 59	96	93
14	11	36,300	9	8	2½	3	112 × 59	96	93
14	12	43,200	10	9	2½	3	115 × 65	101	100
14	13	50,700	10	9	2½	3	115 × 65	101	100
14	14	58,800	12	10	2½	3	111 × 66	111	104
16	7	14,700	6	5	2½	3	107 × 39	76	61
16	8	19,200	8	7	2½	3	112 × 52	89	80
16	9	24,300	8	7	2½	3	112 × 52	89	80
16	10	30,000	9	8	2½	3	116 × 59	96	100
16	11	36,300	9	8	2½	3	116 × 59	96	100
16	12	43,200	10	9	2½	3	118 × 65	101	107
16	13	50,700	10	9	2½	3	118 × 65	101	107
16	14	58,800	12	10	2½	3	115 × 66	111	112
18	8	19,200	8	7	3	4	113 × 52	89	84
18	9	24,300	8	7	3	4	113 × 52	89	84
18	10	30,000	9	8	3	4	118 × 59	96	104
18	11	36,300	9	8	3	4	118 × 59	96	104
18	12	43,200	10	9	3	4	120 × 65	101	112
18	13	50,700	10	9	3	4	120 × 65	101	112
18	14	58,800	12	10	3	4	117 × 66	111	117

PLATE IX.



117.—Tangye's Duplex Piston-Pump—300-feet series.

[*To face p.* 170

4.—TWO STEAM-CYLINDER, NON-EXPANSIVE, NON-CONDENSING ENGINES WORKING DOUBLE-ACTING RAM-PUMPS.

'Duplex' Pumps.

The pumps last described, in common with all pumps of the piston class, yield precedence to those of the ram or plunger class for underground purposes.

The 'Worthington' Plunger-Pump.

Various types of this pump are made, but in the 'Scranton Mine Pattern' we have perhaps the best type for heavy mining work. Fig. 118 is a longitudinal section, fig. 119 a plan partially sectional, figs. 120 and 121, end views of the water-cylinders, etc., and steam-cylinders, etc., part in section; fig. 122 is a section of pump-valve and seat. It will be observed that this pump belongs to the 'Outside Centre-packed' type of ram-pumps. Nothing further need be said of the design, the excellency of which is sufficiently obvious from the illustrations.

The manufacturers make the following observations: 'In designing this pattern, great care has been taken to reduce as much as practicable the loss by friction inseparable from packed plungers of all forms by adopting such methods of construction as will secure absolute rigidity of alignment under the heavy pressures often encountered by this form of pump. The pumps are made to withstand 200 pounds per square inch water-pressure, and the patterns are so subdivided that the rupture, from any cause, of any one part only necessitates the renewal of a comparatively small casting.'

The 'Lehigh' pattern is an admirably designed pump of the 'Outside-packed' (two single-acting plungers) class, a type which has already been fully described. This pattern has been especially designed to withstand the heavy pressure encountered in deep workings, and is recommended where a working pressure greater than 200 pounds to the square inch is to be overcome, or where, on account of bad water, it is not desirable to use valve-seats which are screwed into the valve-plates. The water-valves are arranged in a series of valve-boxes or pot-chambers, each chamber containing one or more small valves having a low lift, and easily accessible by screwing back the nuts on the swing bolts and removing the valve-box covers. The valve-seats are forced into place on a slight taper. The valves

are of brass faced with leather, guided from below by wings and controlled by composition springs held in place by the valve-box covers. This arrangement eliminates all screw-threads from that portion of the pump coming into contact with the mine water.

The following are the standard sizes of Worthington plunger-pumps, but any other combination can, of course, be made; we have omitted sizes below 14-inch steam-cylinders.

Dia. of steam cylinders	Dia. of water cylinders	Length of stroke	Water per hour at ordinary speed	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe
in.	in.	in.	gall.	in.	in.	in.	in.
14	7	10	20,100	6	5	2½	3
14	8½	10	29,400	6	5	2½	3
14	10¼	10	42,000	8	7	2½	3
14	7	15	24,000	6	5	2½	3
14	8½	15	36,000	6	5	2½	3
16	7	10	20,100	6	5	2½	3
16	8½	10	29,400	6	5	2½	3
16	10¼	10	42,000	8	7	2½	3
16	12	10	58,800	10	8	2½	3
17	7	15	24,000	6	5	3	3½
17	8½	15	36,000	6	5	3	3½
17	10¼	15	51,000	8	7	3	3½
17	12	15	70,500	10	8	3	3½
18½	7	10	20,100	6	5	3	3½
18½	8½	10	29,400	6	5	3	3½
18½	10¼	10	42,000	8	7	3	3½
18½	12	10	58,800	10	8	3	3½
20	8½	10	29,400	6	5	4	5
20	10¼	10	42,000	8	7	4	5
20	12	10	58,800	10	8	4	5
20	8½	15	36,000	6	5	4	5
20	10¼	15	51,000	8	7	4	5
20	12	15	70,500	10	8	4	5

Pearn's 'Duplex' Plunger-Pump.

Fig. 123 is an elevation of this pump, to which is applied the maker's 1893 patent system of packing, which enables the plungers to be packed in the same manner as an ordinary single-acting pump. This pump, it will be observed, belongs to the 'Outside Centre-packed' class, one plunger, with a direct centre-connection, delivering from each end.

Evans's 'Cornish' Duplex Plunger-Pump.

Messrs. Jos. Evans & Sons, of Wolverhampton, are well-known manufacturers of engines of tbe Duplex type for underground use. It will be remembered what conspicuous service was rendered by a pump of this class at the Dungannon Colliery, when it was flooded a few years since by

PLATE X.

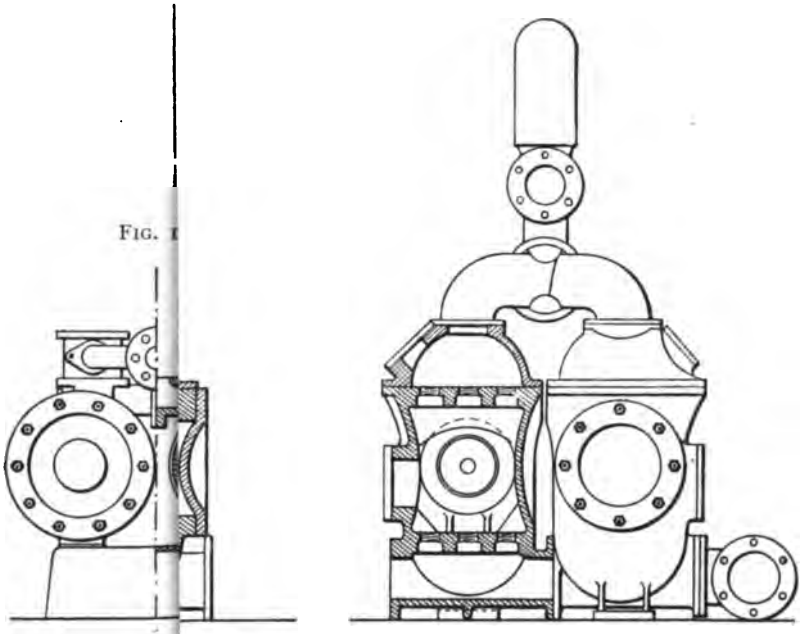


FIG. 120.

FIG. I

FIG. I

evations, and Section of Water Valve.

[To face p. 172.

a great inrush of water. The incident is thus referred to by Messrs. Jos. Evans & Sons in a letter to the author, dated November 21, 1898 :—

'As near as we can remember the water rose to a height of 60 feet above

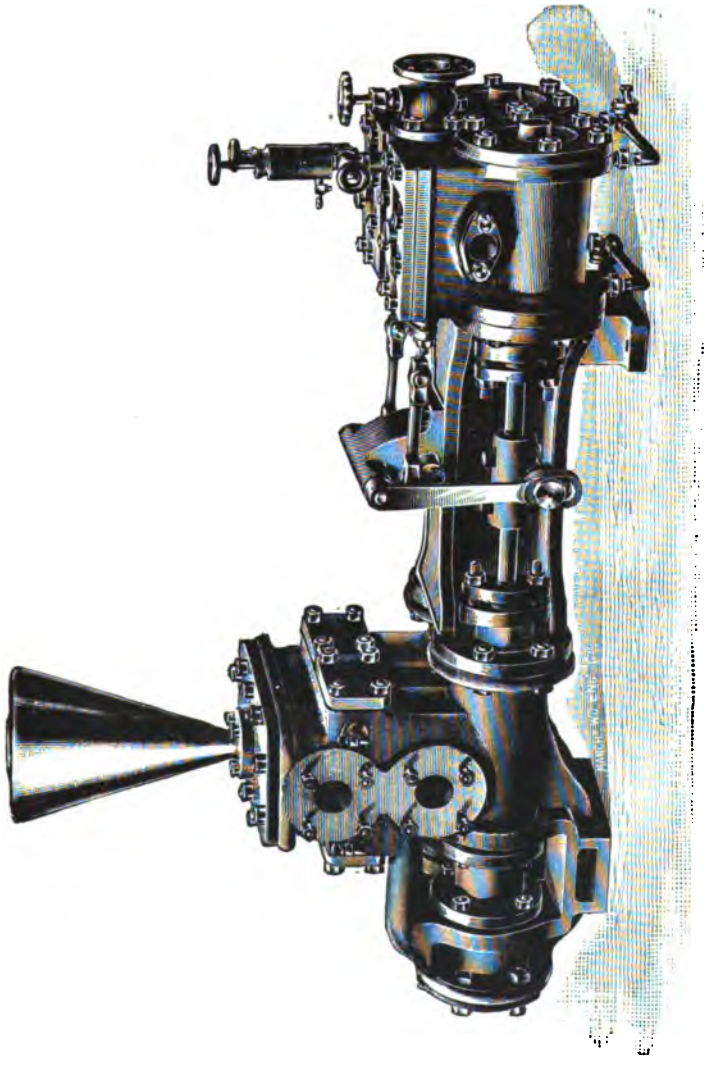


FIG. 123.—Pearn's Duplex Plunger-Pump.

the pump. The steam was carried from the boilers down the mine a distance of about 1,000 feet, and the exhaust happened to be carried through one of the roads into the upcast shaft, but we are not sure whether the end of the exhaust pipe was covered with water or not; at all events the

engine was set to work by turning on steam from the boilers, and continued to work under steam for several days, eventually pumping itself dry and recovering the mine.

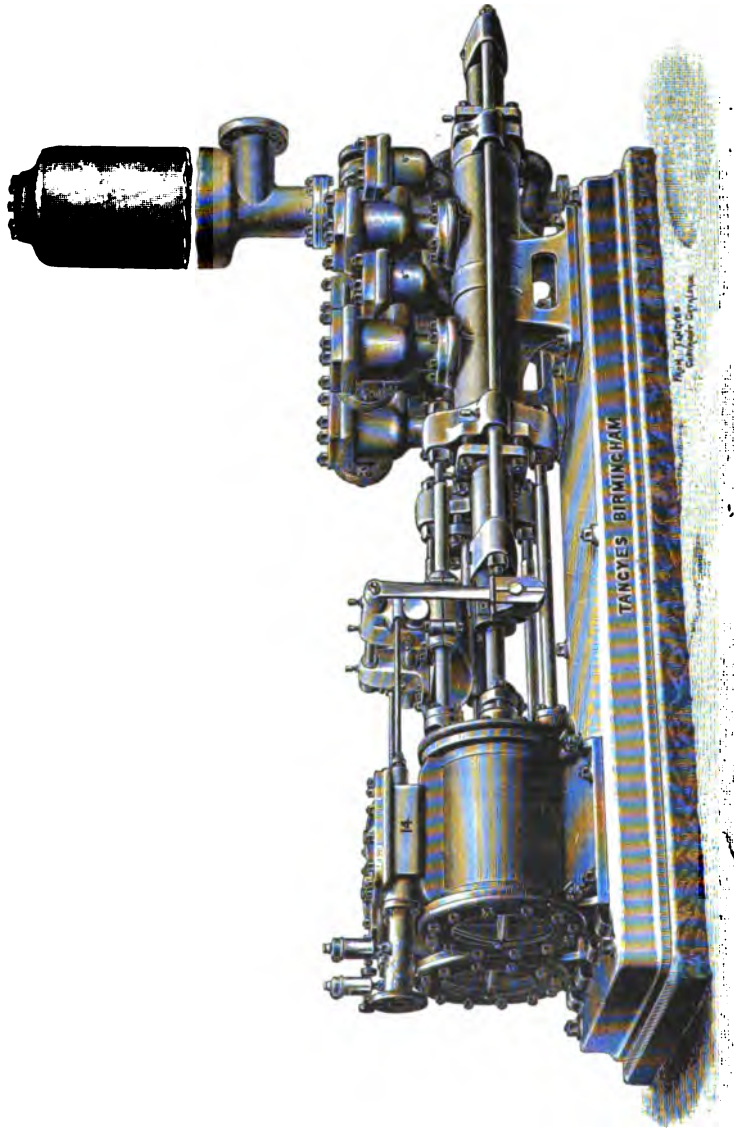


FIG. 124.—Tangyes' 'Duplex' Plunger Pump; 600-feet series.

'The engine was one of our patent "Cornish" Duplex Horizontal Pumping Engines, with two 21-in. diameter steam cylinders, two 7-in.

diameter double-acting rams, all 36-in. stroke, and was put in to raise 20,000 gallons of water per hour 420 feet high, with 30 lbs. per square inch steam pressure. The original cost was about £400. A surface condenser has since been added to take the exhaust steam from this engine, and from also an additional one of the same make but smaller size.'[1]

TANGYES' 'DUPLEX' PLUNGER-PUMP.

The pump represented by fig. 124 is an example of the 'Outside-packed' (two single-acting plungers) class, with a central connection for the front plunger and a side connection for the rear plunger, each delivering from its inside end. The illustration is from a photograph of the 14 × 6 × 12 size, 600-feet series.

The standard sizes above 12-inch steam-cylinders are as follows, the stroke of each pump being 12 inches :—

Dia. of steam-cylinders	Dia. of water cylinders	Water per hour at speed of 75 ft. per minute	Dia. of suct'n and del. pipes	Dia. of steam-pipes	Dia. of exhaust pipes	Length and width	Height to top of air-vessel
in.	in.	gals.	in.	in.	in.	ft.	ft.
13	5	7,500	4	2½	3	12¾ × 4½	9
13	6	10,800	4	2½	3	12¾ × 4½	9
13	7	14,700	5	2½	3	13½ × 4½	10¼
14	5	7,500	4	2½	3	12¾ × 4½	9
14	6	10,800	4	2½	3	12¾ × 4½	9
14	7	14,700	5	2½	3	13½ × 4½	10¼
14	8	19,200	6	2½	3	13¾ × 4½	11
16	5	7,500	4	2½	3	13 × 4½	9
16	6	10,800	4	2½	3	13 × 4½	9
16	7	14,700	5	2½	3	13¾ × 4½	10¼
16	8	19,200	6	2½	3	14 4½	11
18	6	10,800	4	3	4	13½ × 4½	9
18	7	14,700	5	3	4	14 × 4½	10¼
18	8	19,200	6	3	4	14 × 4½	11

[1] The incident is thus referred to by *Engineering*, January 10, 1896 :—'A few weeks ago the Dungannon Colliery, Ireland, was inundated by an enormous body of water tapped from some old workings. The pumps were drowned out. Since then, however, they have been successfully set to work, though submerged under 60 ft. of water.'

5.—SINGLE STEAM-CYLINDER, EXPANSIVE, CONDENSING ENGINES WORKING DOUBLE-ACTING RAM-PUMP.

Although classed as expansive, these engines, when used underground for deep drainage, are only expansive to a very small extent. Without a high initial pressure of steam and a moving mass much greater than the mean water-load, to absorb the excess of pressure at the beginning of the stroke, and a great piston speed or, in the absence of a great moving weight, a high initial pressure of steam at a great speed, and a steam-cylinder of a diameter very largely in excess of that of the water-cylinder, it is impossible to get any appreciable expansion from engines of this class. Without a condenser the steam can only be expanded down to the water-load, but in no case below the pressure of the atmosphere. If, for instance, the steam be supplied at 60 lbs. per square inch and the water-load be 20 lbs., the steam may be expanded to about 22 or 23 lbs. per square inch, and then lost. It will thus be seen that although expansion is possible in these engines, it is always attended with a comparatively great loss of steam.

The application of the condenser permits the ratio of expansion to be increased, and effects a great saving of steam. The vacuum produced would remove a back-pressure generally exceeding 7 or 8 lbs. per square inch, and sometimes as much as 12 or 13 lbs., depending upon the quality of the vacuum, and the steam could be expanded to nearly that extent below the mean water-load, a small margin being necessary for the friction of the machinery and the water through the pipes. For a further consideration of this subject see p. 178.

Davey's Patent 'Differential' Engine.

This engine works a double-acting ram-pump, and is specially adapted to forcing to great heights, and pumping water containing grit or mud.

It is made in various sizes ranging from 10 to 50-inch steam-cylinders; the largest made appears to have been one of 52-inch cylinder. The pump-rams vary in size from 4 to 12 inches in diameter, with a stroke of from 2 to 5 feet. Any combination in the sizes of the cylinder and rams and the length of the stroke can be made. This engine has been made both condensing and non-condensing; in the former case the steam is condensed by means of a patent separate condenser, the air-pump

of which is sometimes worked by the pressure of water in the main column.

The following are examples of the condensing type of this engine in use in collieries :—

One engine, with 12-inch cylinder, 20-inch stroke, to raise 6,000 gallons per hour 250 feet.

One engine, with 19-inch cylinder, 20-inch stroke, to raise 15,000 gallons per hour 300 feet.

One engine, with 18-inch cylinder, 24-inch stroke, to raise 18,000 gallons per hour 135 feet.

One engine, with 22-inch cylinder, 24-inch stroke, to raise 12,000 gallons per hour 480 feet.

Two engines, with 26-inch cylinders, 36-inch stroke, to raise 78,000 gallons per hour 240 feet.

One engine, with 30-inch cylinder, 36-inch stroke, to raise 18,000 gallons per hour 480 feet.

The following is a table of sizes and capacities of some of these engines :—

Dia. of steam cyl.	Dia. of plunger	Length of stroke	Water per hour	Dia. of steam pipes	Dia. of suction and delivery pipes	Height water can be raised with 40 lbs. boiler pressure
in.	in.	in.	gall.	in.	in.	ft.
20	6	36	8,640	3½	4½	713
22	7	48	13,692	3½	6	627
24	6	48	10,089	4	5	1,027
26	7	48	13,692	4	6	876
28	9	60	25,920	4½	8	615
30	7	60	15,650	5	6½	1,150
34	10	60	32,000	5½	9	737
36	9	72	29,200	6	8½	1,017
40	8	72	23,000	6½	7½	1,600
50	12	72	48,210	8	11	1,105

THE 'SELF-GOVERNING' ENGINE.

Having elsewhere (p. 149) fully described the non-condensing type of this engine, it will not be necessary to make any further reference hereto.

B.—COMPOUND STEAM-PUMPS.

In dealing with the simple pumps of this, the horizontal non-rotary group, we observed that the piston was moved by steam at full pressure the whole length of the stroke, the steam being then wasted. When made condensing by the provision of a suitable and efficient condenser, a course often and wisely adopted in the case of the larger engines, there is an appreciable gain by the relief of back-pressure. But the practice of using a single-cylinder engine, whether condensing or non-condensing, is so incompatible with economy, that the extension of this principle of pumping to engines of a large size, and for permanent duty, would incur an extravagant consumption of fuel, hence the adoption of a combination of steam-cylinders by which the steam could be used expansively, and at higher pressures.

Occasional further reiteration in pursuing the subject must be forgiven in view of its great importance, and the desirability at this point of considering it with greater amplitude than has hitherto been necessary. Without a considerable piston speed and a heavy inert mass (which by, first, its inertia, and afterwards, its momentum, compensates for the diminution in the pressure of the steam), or a steam-cylinder wastefully disproportionate in size compared with the water-cylinder, an excessive pressure of steam at the beginning of the stroke, and a great speed, it is impossible to work underground single-cylinder engines expansively to an appreciable degree. It is, therefore, evident that engines of this class can only be worked expansively to a very limited extent, and in any case there will be a great loss of steam, as it must be exhausted at a pressure exceeding that of the atmosphere. It will thus be apparent that under the circumstances in which these engines are used, no device for making them expansive can prevent a comparatively great loss of steam, but the use of a condenser would permit the steam to be condensed at a considerably lower pressure. This is obtaining expansion at a rather dear price; and there is another reason against this unnatural and manufactured expansion. It is quite evident that the attempt to impart by mere pressure of steam and speed sufficient momentum to a light reciprocating body to overcome a resistance that is practically constant leads to a jerky and irregular action of the piston, which goes forward with a bound; the result must be highly prejudicial to the machine. Smoothness and regularity of action are sacrificed,

and sooner or later there must be a breakdown. It is thus apparent that in the single-cylinder engine we cannot have both certainty of action and expansive working; the latter is, under the circumstances, such a doubtful benefit that steam users prefer dispensing with it. A supplementary cylinder, to receive the high-pressure steam after it leaves the first cylinder, becomes a necessity for a ratio of expansion that shall be at once economical and safe.

There is little advantage in using a compound engine for steam pressures lower than 80 lbs. per square inch. For pressures ranging, say, from 130 to 150 lbs. a triple-expansion engine must be employed to achieve the maximum economy attainable.

In a prospectus of their compound pump the makers of one of the most extensively used simple pumps state thus: 'For confined situations, or where engines of a comparatively small size only are necessary, they (the simple pumps) will still meet all requirements, but their application will be very largely increased, since it has been found practicable to embrace the important features of expanding and condensing the steam, so that increased power may be obtained, and the consumption of fuel greatly economised.'

So far are these engines, when properly proportioned, and using steam of a high pressure, removed from the single-cylinder engines in respect of economy, that their adoption in collieries may be justifiable even when economy of fuel is a matter of some moment, although, of course, an underground engine can never be so economical as a surface engine. This may be taken as an axiom.

These machines are of a more imposing character than the simple pumps, being applied to more extensive drainage operations, and in their construction they are perhaps the most compact and the simplest forms of machinery for raising water which make provision for the expansion and condensation of the steam.

The available boiler pressure, the load to be moved, and the degree of expansion required, are the factors which determine the relative size of the high- and low-pressure cylinders. The proportion varies in practice from 1 for the diameter of the high-pressure cylinder to 1·75 for that of the low-pressure cylinder, to, in extreme cases, 1 to 2·5. The usual ratio appears to be 1 to 1·75. The average of thirty underground engines made by Messrs. Hathorn, Davey, & Co. is 1 to 1·783, the area ratio of which is 1 to 3·179.

The steam enters the smaller cylinder at a high tension, and having pressed the first piston to the end of the stroke, escapes into a jacket, or into a low-pressure casing, whence it then enters the larger cylinder, and completes its work there by expansion, being finally condensed in the usual manner. In the combination of the compound engine in which the pistons of the two cylinders are connected to cranks at right angles to each other, on the same shaft, an intermediate receiver is provided. This takes the steam exhausted from the high-pressure cylinder and supplies it to the low-pressure cylinder, in which it is cut off and then expanded to the end of the stroke.

There are two leading types of the compound engine, differing the one from the other in the manner of dealing with the steam from its exhaustion from the high-pressure cylinder. In the type represented by the Woolf engine the steam is exhausted practically direct from the high-pressure into the low-pressure cylinder; in the second type, known as the 'receiver-engine,' the steam is exhausted into a receiver and thence is supplied to the low-pressure cylinder, as already stated.

For mining purposes these engines are generally arranged 'tandem,' *i.e.*, the two steam-cylinders and pump-cylinders are in a line, the low-pressure cylinder usually being between the high-pressure and pump-cylinders. The steam-cylinders have a piston-rod common to both, and attached to the pump-piston, or ram, as the case may be, in the same line. In Mr. Davey's 'Differential' and the 'Self-Governing' engines there are two piston-rods to the low-pressure piston, which are united to a high-pressure piston and pump piston-rods by a crosshead, the high-pressure cylinder in these machines being next to the pump. Each steam-cylinder has a steam-chest and a set of valves receiving independent motion from their respective steam-cylinders. The peculiarity of the 'Self-Governing' engine consists in the arrangement of the valve gear, which is Messrs. Cope and Maxwell's patent, and, like Mr. Henry Davey's, it acts upon the principle of controlling the rate of movement of the engine by the flow of a liquid from one end to the other of a cataract-cylinder.

We purpose to notice in detail the 'Differential' valve gear: the 'Self-Governing' valve gear has already been described. In Cherry's pump the low-pressure cylinder surrounded the high-pressure, one ordinary flat-faced slide-valve and one steam-chest only being used for both, while the space occupied was no more than that of an ordinary single-cylinder engine.

Sturgeon's pump consisted of a low-pressure cylinder in a straight line with the pump, combined with a pair of high-pressure cylinders, one on each side of the low-pressure.

The pumps of Messrs. Field and Cotton and Mr. Walker were very peculiar, being novelties in the way of compound engines. The former was exhibited in model form at the Vienna Exhibition in 1873. It consisted of a high-pressure cylinder placed within a low-pressure, the former moving forwards and backwards upon a fixed piston attached to a piston-rod.

Walker's pump consisted of a steam-cylinder with an annular partition fixed at the centre of its length. A barrel of considerable length, with piston-heads at each end, was fitted into the cylinder; the barrel part worked steam-tight in the latter. This machine, like that of Field and Cotton, would require drawings and a detailed description to make any account of it intelligible.

In pumps such as Cherry's and Sturgeon's a great saving in length was effected compared with those which have the cylinders end to end. This is an important feature in mining pumps for use underground, where the

space available is often very limited; it also effects a considerable saving in foundations. The dimensions of Sturgeon's pump of two high-pressure cylinders, 11 inches diameter, and one low-pressure of 26 inches diameter, with a 2-feet stroke, working two 7-inch double-acting rams, were: length over all, 13 feet 8 inches; width, 5 feet 2 inches; height to the top of the air-vessel, 8 feet. A pump of this size was capable of throwing 10,000 gallons per hour 600 feet.

It will be observed that the references to Cherry's, Sturgeon's, and other engines are in the past tense; the reason for this is their withdrawal from the market. The interest which always attaches to experimentation, and the educational value of failure as well as of success in this as in all other fields of industrial art, will doubtless be accepted as a sufficient *raison d'être* for these notes, and the more detailed references at a subsequent page, on defunct machines.

Compound engines, non-condensing, have come into extensive use in the past few years, but are obviously not suitable for underground use, for the same reason that makes a non-condensing single-cylinder engine objectionable, namely, the nuisance, the trouble, and the inconvenience caused by the exhaust steam in the shaft and workings, which, in a large engine, would be unendurable.

Sizes and Weights.

The following are standard sizes of leading makers, suitable for a maximum head of 300 feet, and a maximum steam-pressure of 120 lbs. per square inch; engines below 9 × 16 steam-cylinders are omitted. The stroke of each pump is 2 feet. When these pumps are to work with steam pressures of from 70 to 90 lbs. per square inch, the high-pressure cylinders are made slightly larger in order to reduce the ratio of the cylinders to suit the lower pressures:—

Dia. of high pressure cyl.	Dia. of low pressure cyl.	Dia. of water cyl.	Water per hour	Dia. of suction and del. pipes	Dia. of steam pipe	Dia. of exhaust pipe	Length and width (app.)	Height to top of air vessel (approx.)	Weight (apprx.)
in.	in.	in.	gall.	in.	in.	in.	in.	in.	cwts.
9	16	12	28,800	9	1½	3½	141 × 43	95	64
9	16	14	39,200	10	1½	3½	141 × 47	104	75
10	18	8	12,800	6	1¼	4	137 × 38	82	55
10	18	9	16,200	7	1¼	4	138 × 42	88	60
10	18	10	20,000	8	1¼	4	142 × 45	93	65
10	18	12	28,800	9	1¼	4	143 × 47	95	71
10	18	14	39,200	10	1¼	4	143 – 51	104	82
12	21	9	16,200	7	2¼	5	148 × 43	89	73
12	21	10	20,000	8	2¼	5	149 × 46	94	77
12	21	12	28,800	9	2¼	5	150 × 48	95	82
12	21	14	39,200	10	2¼	5	151 × 52	105	93
14	24	10	20,000	8	2½	5½	151 × 47	95	91
14	24	12	28,800	9	2½	5½	152 × 50	95	96
14	24	14	39,200	10	2½	5½	153 × 53	105	107

Dia. of high press. cyl.	Dia. of low press. cyl.	Dia. of water cyl.	Length of stroke	Water per hour	Dia. of suction and del. pipes	Dia. of steam pipe	Dia. of exhaust pipe	Price	Approx. weight packed	Approx. lift per lb. pressure in h.p. steam chest	
in.	in.	in.	in.	gall.	in.	in.	in.	£	cwts.	ft.	in.
10	20	4	18	3,200	3	1¾	2¼	115	32	16	0
10	20	6	18	7,300	4	1¾	2¼	126	36	7	0
10	20	8	18	12,800	6	1¾	2¼	132	40	3	10
10	20	4	24	3,200	3	1¾	2¼	145	37	16	0
10	20	6	24	7,300	4	1¾	2¼	152	43	7	0
10	20	8	24	12,800	6	1¾	2¼	158	47	3	10
10	20	10	24	20,000	8	1¾	2¼	175	50	2	6
12	22	4	18	3,200	3	2¼	3	130	36	20	0
12	22	6	18	7,300	4	2¼	3	136	40	10	0
12	22	8	18	12,800	6	2¼	3	149	46	5	0
12	22	10	18	20,000	8	2¼	3	157	50	3	10
12	22	4	24	3,200	3	2¼	3	156	46	20	0
12	22	6	24	7,300	4	2¼	3	169	49	10	0
12	22	8	24	12,800	6	2¼	3	182	56	5	0
12	22	10	24	20,000	8	2¼	3	195	62	3	10
12	22	12	24	29,000	9	2¼	3	221	70	2	6
14	26	8	24	12,800	6	2½	3¼	214	56	7	6
14	26	10	24	20,000	8	2½	3¼	247	57	5	2
14	26	12	24	29,000	9	2½	3¼	260	76	3	6
14	26	12	36	29,000	9	2½	3¼	344	95	3	6

These pumps can be made of any size, and any combinations can be made between the steam and pump-cylinders. The smallest and largest sizes advertised by makers vary from 6 × 14 inches to 35 × 60 inches for the high and low-pressure steam-cylinders respectively, and from 3 to 14 inches for the pump-cylinders. The length of the stroke ranges from 2 to 6 feet.

The quantity of water (which is approximate) is calculated in each table on a piston speed of 100 feet per minute, which for ordinary use should be considered the maximum. The speed, however, can be varied from 10 feet per minute upwards. A deduction must be made from the theoretical quantity of water to allow for loss by leakage, slip, etc.

Capabilities.

By referring to the tables of the sizes, etc., the reader will observe the quantities of water that may be raised by engines of given sizes. The 'Differential' compound steam-pump of Mr. Henry Davey, of Leeds, has been made for use underground in sizes as large as 35 inches high-pressure cylinder, and 60 inches low-pressure cylinder, with a 6-feet stroke, and capable of delivering more than 40,000 gallons per hour about 900 feet high.

The 'Tangye' double-ram compound engine (21 × 36 steam-cylinders, 12-inch rams, and 4-feet stroke), supplied to the Chesterfield and Boythorpe Colliery Company, was set to work at 400 feet below the surface, and steam at a pressure of 45 lbs. per square inch was taken down to it. A speed of 28 strokes per minute (equal to 224 feet) could be obtained without difficulty. The gauge on the condenser showed a vacuum varying from 11½ to 13 lbs.

The following is an account of the work done by engines of the compound 'Differential' type, applied underground in collieries.

Cylinders		Stroke	Particulars of work
High press.	Low press.		
in.	in.	in.	
33	50	72	To raise 37,200 gallons per hour 1,290 feet
22	54	72	A pair, each to raise 30,000 gallons per hour 920 feet, and to give power to an hydraulic engine which lifts 30,000 gallons per hour 64 feet
25	50	60	30,000 gallons per hour 450 feet
28	50	60	24,000 gallons per hour 1,100 feet
33	54	72	3, each to raise 60,000 gallons per hour 345 feet
35	60	72	A pair, each to raise 42,000 gallons per hour 910 feet
33	54	72	To raise 72,000 gallons per hour 300 feet

The illustration, fig. 125, represents Mr. Davey's system of draining collieries and other mines, as carried out on a large scale in a colliery 1,200 feet deep.

At a point in the pit 900 feet from the surface are placed a pair of compound 'Differential' engines, pumps, and a separate condenser. The engines have cylinders 35 inches and 60 inches in diameter, and a 6-feet stroke. The pump-rams, which are of gun-metal, are 12½ inches in diameter. At the bottom of the pit, 300 feet below the main engines, are placed a pair of hydraulic pumping engines, which are to lift 60,000 gallons per hour to the main engines. The latter force the water to the surface and supply power through the column to the hydraulic engines. By this system the main engines are kept out of danger of flooding. The hydraulic engines will work under water, and can be actuated from the main engine-room. As further security, they could be placed in a water-tight chamber, accessible from the main engine-room, through a water-tight staple. By such means the hydraulic engines could be under repair even if the water rose to the main engines, 300 feet up the shaft. The principle of its action is that of employing water at a given head to raise a larger quantity against a less head.

'Dip workings are drained by means of hydraulic engines applied on the same principle . . . and a great number are working very successfully in various collieries. The useful effect is about 80 per cent. of the power applied.'

We have already stated that these engines are generally supplied with steam from the surface. The reasons for preferring to do this to giving them steam from boilers alongside are stated at p. 83. Of course loss from condensation in the latter case is avoided, but the disadvantages more than counterbalance this gain. It is possible to use compressed air, but its useful effect is much less than that of steam.

'These engines are not so suitable for metalliferous mines as they are for collieries. In many collieries one shaft is made to serve the double

purpose of pumping and winding, and there is not sufficient room for the pump-rods and the winding apparatus, and the underground engine in such a case becomes almost a necessity. The extra amount of steam used by the condensation in the pipes is more than fully compensated by the advantages of having no rods in the pit to interfere with the winding arrangements, and of having a very much smaller amount of machinery to do the work. Underground engines and pumps are very much smaller than those on the surface, because the absence of rods enables them to be driven at much higher speeds.'

It must be borne in mind that it is not practicable to sink pits with engines of this description without additional pumping apparatus, their sphere being limited to collieries where the required depth has already been attained. We say *collieries* advisedly, because the cost of fuel prevents the use of large underground engines in metalliferous mines (see below and also pp. 96 and 102).

Cost.

A very important consideration in the use of steam engines is their first cost, but the weight to be attached to this feature will depend very much upon circumstances. In collieries where large quantities of unsaleable slack are at command, or other low quality coal which costs perhaps only a few pence per ton to raise, the first cost of an engine is thought to be of more consequence than its working results; but in a metalliferous district, such as Cornwall, with the cost of coal at 15*s.* per ton, the first cost is of secondary importance, and the supreme effort is how to get the water out of the mine with the smallest consumption of coal. The heaviest item of 'dead cost' in a metalliferous mine is generally that of pumping. It is evident under such circumstances that an economical engine compared with a less economical one would ultimately pay the excess of first cost, the length of time depending upon the relative economical values of the engines.

Another phase of the question has to be considered. It sometimes happens that the convenience which attends the using of an engine of a particular kind will compensate for its inferior economy. This is especially the case with some forms of underground engines which can be used in places and under circumstances where it would not be easy nor even perhaps possible to use any other kind of engine. In this case we have not only the greater convenience but the lesser first cost of the engine. These are features of the question which we have already considered, and which the capitalist must ponder in the choice of machinery for the unwatering of mines.

In order to give the relative cost of the different engines it will be necessary to arrive at the cost of engines for the performance of a given quantity of work. We will assume then that the quantity of water to be raised is 30,000 gallons per hour, and the height 1,800 feet, which is about

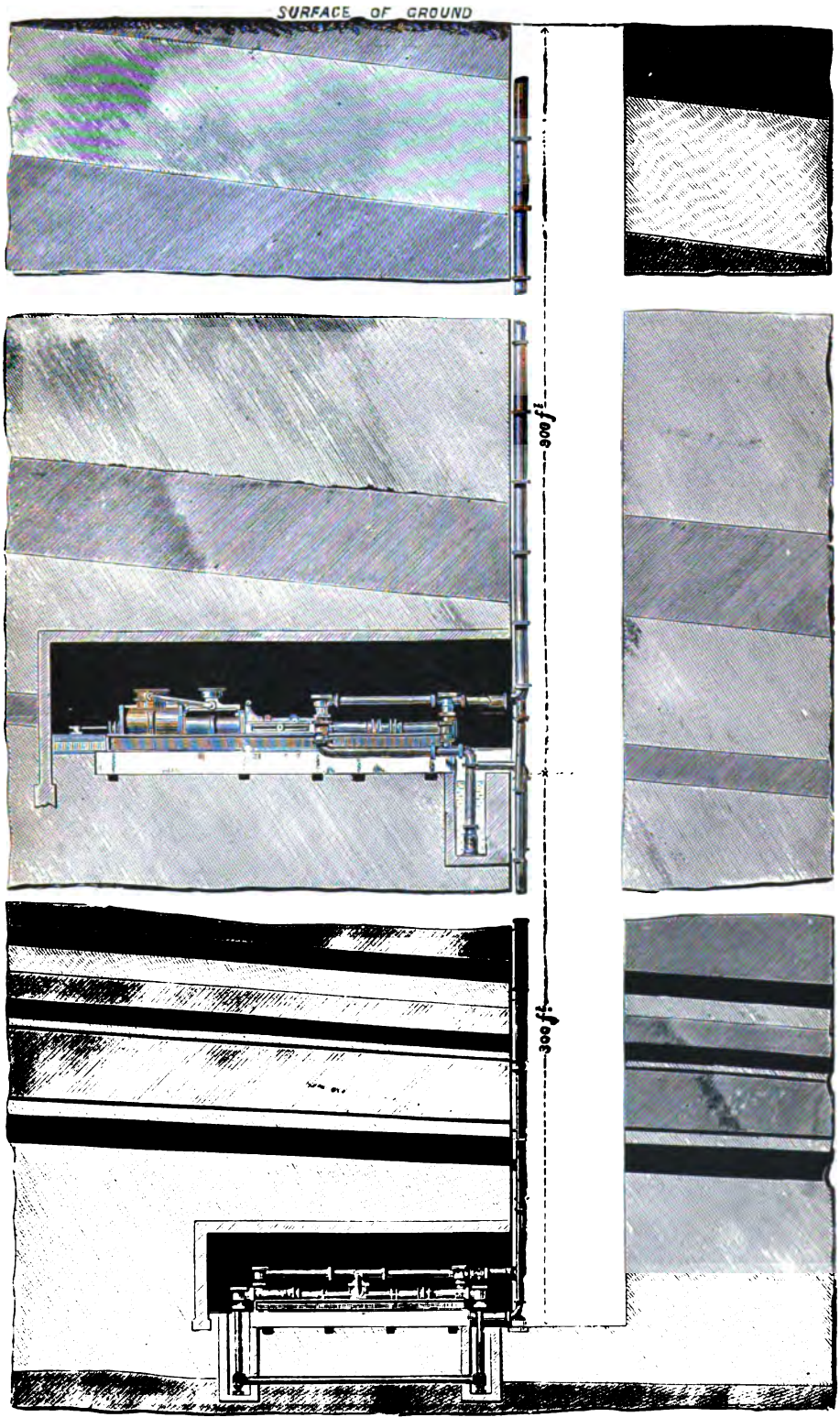


FIG. 125.—Davey's 'Differential' Compound Engine; section showing mode of applying main and hydraulic engines underground.

[*To face p.* 184.

the depth of some of the deeper mines in Cornwall (from the adit) and many of the coal mines.

A Cornish engine of the following dimensions would be required for the performance of the quantity of work stated—

	tons	£
95-inch cylinder, 11-feet stroke in the cylinder, and 10-feet in the shaft, working at 8½ strokes per minute	133	3,500
Erecting ditto and boilers		400
Four 12-ton boilers, outfits and pipes	72	1,440
Engine and boiler houses		900
	205	£6,240
PITWORK.		
Pitwork 13½ inches, 6 plunger-lifts, each 50 fms.	195	2,500
Fixing ditto		380
Rods averaging 17 inches square	65	750
Rod-plates and bolts	60	1,100
2 balance-beams	22	440
	342	£5,170
Total	547	£11,410

The following is an estimate of the cost of an underground compound engine and pumps and hydraulic engine, for the same work.

	tons	£
Engine and pumps	50	1,750
Hydraulic engine	12½	600
Steam and water pipes	160	1,900
Boilers	40	1,400
Buildings, excavation, etc.	—	1,150
	262½	£6,800

The estimate of the underground engine only applies when the pit is *already sunk*. Till then, the engine must be used at surface, as already stated, and be afterwards taken underground and the pumping apparatus thrown aside and new substituted. If the first cost of the engine, and the cost of removing it and the pump-work, and the cost of new pump-work, be added, the total would probably reach that of the Cornish engine. Moreover, the working economy of the underground engine not being nearly so good as that of the Cornish, it is evident it will not bear a comparison with the latter for sinking operations. The circumstances which necessitate the adoption of underground engines in collieries already down to the required depth are noticed at page 225. The following is the cost of Davey's Surface Engine at the South Durham Colliery.

'Cylinders, 45 and 72-in., 10 feet stroke. Actual h. p. 550; 10 strokes per minute; plungers 20 in. dia., column 18 in. Work 156,000 gallons

per hour raised 700 feet. Weight of quadrants 25 tons, pumps 60 tons, column 100 tons, and engines 66 tons. The cost of the engine and pumps was £6,000, and foundation and engine-house £600 – total £6,600.'

'A Cornish engine for the same work: Cylinder, 100-in.; stroke 10 feet; strokes per minute 10; plungers 28½ in. dia.; column 26 in. Engine 160 tons; pumps 220 tons. The cost of the engine and pumps would be £6,700, and foundation and engine-house £1,000—total £7,700.'[1,2]

An Evans Compound pump, 13 in. dia. high-pressure, and 24 in. dia. low-pressure cylinders, 10-in. double-acting ram, and 36-in. stroke, fitted with independent fly-wheel jet condenser, and capable of raising 20,000 gallons per hour 600 feet, costs about £400, not including erection.

A Compound Duplex-pump, by the same makers, with 18-in. high-pressure, and 36-in. low-pressure steam-cylinders, 14-in. rams, and 24-in. stroke, with independent jet condenser, and capable of raising 72,000 gallons per hour 360 feet, costs about £2,000. A larger compound duplex-engine, with 24-in. and 44-in. high and low-pressure cylinders, and 16-in. rams, 36-in. stroke, fitted with a surface condenser, with two independent 'Cornish' air-pumps for maintaining the vacuum, rams cased with gun-metal and with manganese bronze rods (the water being very bad), capable of raising 180,000 gallons per hour 600 feet, costs about £3,000, without erection.

Description.

These engines are variously arranged; generally the two steam-cylinders and the pump-cylinder are in a line, and when so placed the designation 'tandem engine' is applied. The sequence of the steam-cylinders may be governed by local circumstances and considerations, or decided by the fancy of the engineer. The arrangements for condensing sometimes determine the relative positions of the cylinders. The usual order is—the condenser at one end, the pump at the other, and the steam-cylinders between, the condenser and the low-pressure cylinder being in close proximity for convenience in condensing the exhaust steam.

With a view to minimise the loss of steam in its passage from the one cylinder to the other, to effect a saving in the cost of foundations and reduce the floor space, a matter of some consideration in underground engines, the distance-piece has been dispensed with by bringing the two cylinders close together. In other cases compactness has been carried a stage further by placing one cylinder within the other. Many ingenious devices, some of which are shown opposite, have been originated in this direction, but the results have not been satisfactory. Theoretically, certain of these designs have much to recommend them, but results demonstrate

[1] *Minutes of Proceedings of Inst. Civil Engineers*, vol. liii., session 1877–8, part 3, 'Davey on Pumping Engines,' p. 9.

[2] With largely increased cost of labour and materials the cost of the Davey Surface Engine, pumps, and engine-house now would probably be about £8,000. The figures for the Cornish Engine, etc., originally estimated too low, would now perhaps be for the work named, £10,000.—S.M.

here as in other instances that truth in theory is not always associated with soundness in practice. The difficulties in the examples named are mechanical ones; working and wearing parts are hidden away and cannot be examined or repaired without considerable difficulty and loss of time. Necessarily and unavoidably there are a few moving parts in every engine, such as the piston, steam-valve, etc., which can only be observed by remov ing some portion or portions of the castings. Not only should there be very few such parts, but such as there may be should be as easily and readily accessible as possible. It is herein that these complicated arrangements of cylinders, especially when devoted to underground use, break down. No design that does not provide for the piston-rods being easily

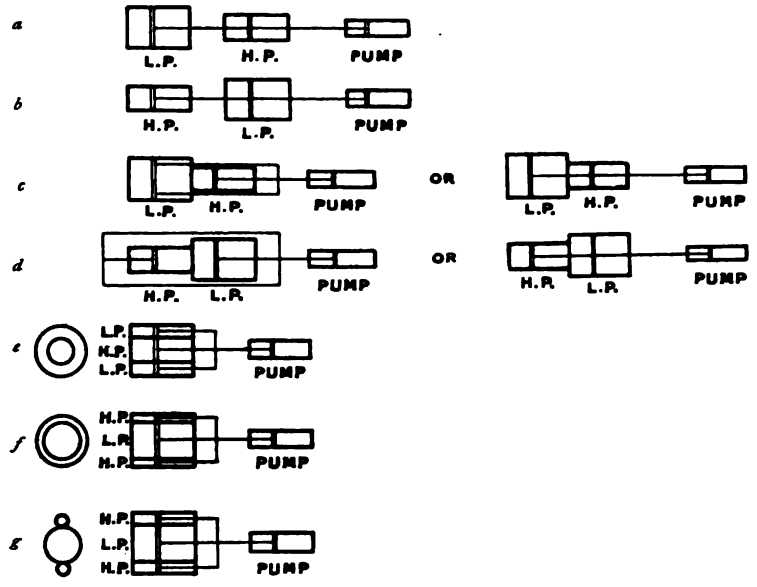


FIG. 126.—Diagrams showing various arrangements of cylinders and piston-rod connections to the pump.

and effectively packed in the stuffing-box, and kept so, and the stuffing-boxes in sight, and the pistons examined by simple removal of the cover, is likely to be satisfactory in practice.

The foregoing plan diagrams (fig. 126) will, perhaps, help to fix in the reader's mind the various methods of grouping the cylinders of engines of this class resorted to by engineers. At *e f g* end views are given in order that the reader may the better comprehend the respective arrangements.

In diagram *a* the low-pressure cylinder is in front of the high-pressure cylinder, with a distance-piece between.

Diagram *b* shows the order reversed, the high-pressure cylinder being in front. This and the preceding example are the most general methods

of arrangement; the piston-rods work through stuffing-boxes in sight, and therefore always open to inspection, and the design admits of a single rod for both pistons and in line with and connected to the pump piston-rod, which is always preferable to a crosshead.

In diagram *c* the two cylinders adjoin, the back end of the low-pressure forming the front end of the high-pressure cylinder, one cover thus doing duty for both at the junction. In this and diagram *d* there is no satisfactory method of keeping the piston-rods lubricated and tight without resorting to a crosshead. The crossheads are manifestly awkward, particularly that of *d*, but in adopting the centre-line connection with the pump in an engine of this type a difficulty arises in packing and keeping steam-tight the piston-rod in its passage from one cylinder to the other.

In diagram *e* the high-pressure is placed within the low-pressure cylinder; diagram *f* shows the low-pressure surrounded by the high-pressure cylinder. In these examples the rods are united by crossheads as shown.

Diagram *g* shows yet another arrangement; the low-pressure cylinder is in the centre line of the pump, and has a high-pressure cylinder on either side. The three piston-rods are attached to a common crosshead, the middle rod being continued through to the pump and taking hold of the pump-rod.

In the 'Self-governing' Compound Engine the valve-gear is precisely the same as that of the Simple 'Self-governing' Engine. The high and low-pressure cylinders and the pump-cylinder are placed in a line, the back end of the high-pressure cylinder forming the front end of the low-pressure cylinder. There are two piston-rods to the low-pressure piston, which work through stuffing-boxes, one on each side of the high-pressure cylinder; these and the high-pressure piston-rod are attached to a crosshead actuating the pump-ram.

In Tangyes' Compound Engines the cylinders are also arranged 'tandem' fashion, the high-pressure cylinder being outside and connected to the low-pressure cylinder by means of a short distance-piece. The slide-valves are actuated from one pair of tappets only, thus ensuring the two valves being reversed together and giving a slight pause at the end of each stroke. The air-pump condenser is placed at the back of the high-pressure cylinder and the whole mounted on a cast-iron baseplate.

In Field and Cotton's 'Direct Expansion' Compound Engine the high-pressure cylinder is placed within a low-pressure cylinder, the former moving backwards and forwards upon a fixed piston attached to a piston-rod, which, passing through a steam-tight bushing in the end of the high-pressure, is fitted into one end of the low-pressure cylinder. The high-pressure cylinder, being fitted with piston-heads at each end, forms a piston for the low-pressure, the annular space between the two piston-heads forming a steam-chamber to which the live steam from the boiler had constant communication. Steam is admitted from the steam-chamber

to the high-pressure cylinder, and thence is discharged into the low-pressure cylinder by a pair of piston-valves connected by a spindle. These are fixed at the bottom of the high-pressure cylinder, and within the piston-heads before mentioned. A pair of piston-valves are mounted upon the low-pressure cylinder, by means of which the steam is exhausted therefrom. Small spindles are provided at the end of the exhaust-valve chest and at each end of the low-pressure cylinder, in a line with the centre of the steam-valve, in order to move the latter and the exhaust-valve. These will only be required in case of any irregularity in the action of these valves.

The high-pressure cylinder making its stroke within the low-pressure requires, of course, that the latter be as long as the high-pressure cylinder and its stroke. The power of both cylinders is transmitted to the pump by a single piston-rod attached to the end of the high-pressure cylinder.

Cherry's engine consisted of one high-pressure steam-cylinder contained within a low-pressure steam-cylinder. The latter had two piston-rods in a horizontal line with the high-pressure piston-rod, and the three were attached to the same crosshead, which also carried the pump-rod. The valve chest was fixed upon the low-pressure cylinder. The slide-valve, of the compound D type, was actuated by a pair of shooting-pistons fitted in a piston-chamber above the slide-valve. Midway between the shooting-pistons a small slide-valve worked transversely over a flat face by means of which the steam was admitted to the back of each shooting-piston alternately. The face for the starting-valve formed part of the distance-piece of the shooting-pistons. A stud in the bottom of the distance-piece was let into the back of the main valve, having an exhaust passage through it, thereby establishing a communication between the shooting-pistons and the main exhaust. On each side (in transverse line) of the exhaust passage referred to, was a longitudinal steam-passage, communicating through the distance-piece, to each end of the piston-chamber.

A lever anchored either to the crosshead or to the distance-bar, between the steam and pump-cylinders, actuated the starting-valve.

In Sturgeon's patent one low-pressure steam-cylinder in the centre line of the pump is combined with a pair of high-pressure cylinders, one on each side of the low-pressure cylinder. The three piston-rods are attached to a common crosshead; the middle rod is continued through to the pump and takes hold of the pump-rod. The condenser is attached to the suction-pipe of the pump.

The valve-box is placed upon the top of the low-pressure cylinder. The steam-valve is of the compound D type, the larger enveloping the smaller, and the semicircular space between the two backs forming a steam passage through which the used steam from the high-pressure cylinders is conducted to the low-pressure cylinder. The valve works on a face with a double set of steam-passages, and an exhaust-branch in the centre, the outer ports communicating, through ports in the cylinder-end covers,

with the two high-pressure cylinders, and the inner ports passing direct into the low-pressure cylinder. Thus the used steam from the high-pressure cylinders is conducted back through the valve from the ends of the high-pressure cylinders to the opposite end of the low-pressure cylinder, finally passing through the exhaust and into the condenser. A pair of small starting-valves work one on each end of the valve face; the spill connecting them passes out through a stuffing-box, and is attached to a tappet-lever, which is actuated at each end of the stroke by a projection on the cross-head. The office of these valves is to furnish steam and exhaust communication to a valve-moving piston in the upper part of the valve-box, which in turn gives the requisite motion to the main valve :—

This engine was stated to possess the following special advantages :— '1st. A great saving in length as compared with end-to-end cylinders, a most important point in mining pumps for underground working, while for other purposes it also enables a considerable saving in foundations. 2nd. Greater simplicity of parts; a single valve and valve gear serving the purpose of two distinct and separate valves and valve-gears on the old system; and, 3rd, is consequently more easy to keep in repair. 4th. Saving in power by avoiding the loss of friction, leakage, &c., attendant upon the extra valve and valve-gear required on the old system. 5th. Considerable saving in power, owing to the immediate and short passage of the steam from the high to the low-pressure cylinders, the loss in pressure, owing to the steam having to fill the long pipe and extra valve-box in the end-to-end cylinder arrangement being avoided. 6th. Saving in steam in its passage to the low-pressure cylinder, by reason of the port through which it passes being 'jacketed' by the high-pressure steam outside it the greater part of the way, and heated the remainder by reason of the high-pressure steam having passed through the port in the previous stroke. On the old system, the ports are not only not 'jacketed,' but are cooled by the passage of the exhaust-steam through them at every stroke.'

A unique arrangement was Walker's engine; it consisted of one steam-cylinder, with an annular partition fixed at the centre of its length. A barrel of considerable length, with piston-heads at each end, was fitted into the cylinder; the barrel part worked steam-tight through the annular partition, the piston-heads also working steam-tight in the cylinder. The latter was formed with the valve-chamber above it. The slide-valve, of cylindrical form, consisted of two parts, connected by a link, with a piston-head at each end fitting the valve-chamber. Each part of the valve was formed with a D passage, which served to establish communication for the flow of steam from the annular spaces between the piston-barrel and the cylinder to the ends of the latter. A groove at the bottom of the piston-barrel, working over a corresponding guide at the bottom of the annular partition, prevented the piston from rotating.

Steam may be condensed in three ways; firstly, by conducting it into the suction-pipe of the pump, or, more effectively, into a condenser attached

thereto, as is often done in the single-cylinder engines described; secondly, by leading it into a receiver into which a jet of water is introduced, and by a suitable contrivance is dispersed in the form of spray in a manner similar to that produced by a 'rose' attachment to a hose or pipe; thirdly, by passing it into a chamber containing a series of small pipes which are kept cold by the constant circulation of water through them. These appliances are known as suction-pipe condenser, jet condenser, and surface condenser respectively. The addition of a proper condensing apparatus increases the power of an engine from 20 to 30 per cent., according to circumstances, or, if additional power be not sought, reduces the consumption of fuel in the same ratio. Some account has already been given of the first-named appliance, but it may well be supplemented by the following remarks by Mr. Behr, and the accompanying illustration which is reproduced from his useful little book.

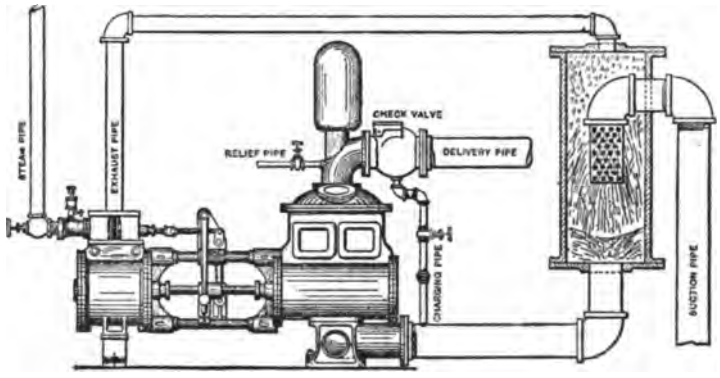


FIG. 127.

'Steam pumps, when used at moderate depth, can have their exhaust steam conducted to the surface. Condensation of the steam exhausted from deeply located underground pump engines is always necessary in order to get rid of the vapour and heat by conveying these to the surface in the water pumped. Sometimes such condensation is carried on at atmospheric pressure, in which case no economy to the engine results. It may be necessary to do this where the mine water is very warm, and advisable in very high altitudes where the barometric pressure is so low as to afford little advantage in extra effective steam pressure. Generally, however, the steam is condensed under a very low pressure in the ordinary manner.

'Condensation of the steam may be carried on either in the suction-pipe, which is the universal practice with sinking-pumps, or by means of an independent condenser with air-pump, like in the case of most of the large station pumping plants.

'Where condensation is effected in the suction-pipe, the steam should enter the latter in a direction almost parallel to the flow of water, so that it

will act like an injector and thus aid in accelerating and lifting the water. . . .

'The amount of vacuum obtainable by this method of condensation depends upon the suction-lift; the greater the latter, the better is the vacuum obtained.

'With horizontal pumps, such as are used at the stations, the suction-lift is usually low, and there is danger of the water rising into the steam-cylinder, particularly when the pump is stopped. A small cock at the upper part of the pipe, opened as soon as the pump is stopped, would prevent this by admitting air and destroying the vacuum. Such cocks are, however, liable to be forgotten, and in some places it has been found safer to drill a small hole into the pipe, which will continually admit some air, at the sacrifice of a part of the vacuum. A better plan is to carry up the exhaust pipe sufficiently high, and then drop it to the condenser, as illustrated in fig. . . . [127], so that the bend will be above the top of the column of water due to barometric pressure. The lowest point of the exhaust pipe can readily be drained by a small pipe running down in a corner of the shaft, with its lower end dipping into a vessel of water placed at such a depth below the exhaust outlet on the cylinder that the outside air cannot force the water up into the exhaust pipe. With vertical sinking-pumps, where the steam-cylinder is located at a considerable height above the condenser, there is usually no danger of the water ever reaching so high, but of course the risk is incurred when the pump is working close down to the water level.

'Station pumps are generally arranged with air-pumps and condensers independent of the suction pipe. In this case, also, the injection valve for the condensing water must be closed as soon as the engine is stopped, so that water may not rise into the steam-cylinder.' [1]

The jet condenser may be what is called 'independent,' that is, the air-pump thereof is operated by an engine quite distinct from, and independent of, the main engine; or it may be operated by an extension of the piston-rod of the main engine. The function of the air-pump, as is well known, is to remove the condensed steam and injected water and air. Fig. 128 is a sectional view of the Worthington Independent Jet Condenser: A is the inlet for condensing water; B, the inlet for the exhaust steam; C, D, E, regulating apparatus for the exhaust steam; F, the condensing chamber; G, air-pump; H, H, inlet valves to the air-pump; I, I, outlet valves from the same; J, discharge branch; K, the steam-cylinder for operating the air-pump; L, valve lever; M, stuffing-box for piston-rod, showing the arrangement for water-packing, viz., a pipe, with a regulating valve for admitting water to the stuffing-box, thus preventing the ingress of outside air to the air-pump. The piston is supposed to be moving from the right to the left; the valve H on the right, being open for the passage of the condensed steam and water into the air-pump cylinder; at the other end the water is being discharged through the valve I on the left, and thence into the delivery-

[1] Hans C. Behr: *Mine Drainage, Pumps, &c.*, pp. 121, 122.

pipe. The connecting passages being on the sides are not shown in the illustration.

The following observations on jet condensers in general, and that named above in particular, are by the makers :—

'Exhaust steam from an engine enters a vacuum with a velocity of about 1,900 feet per second; and water under atmospheric pressure with a velocity of 47 feet per second. Excepting the machine herein described, it

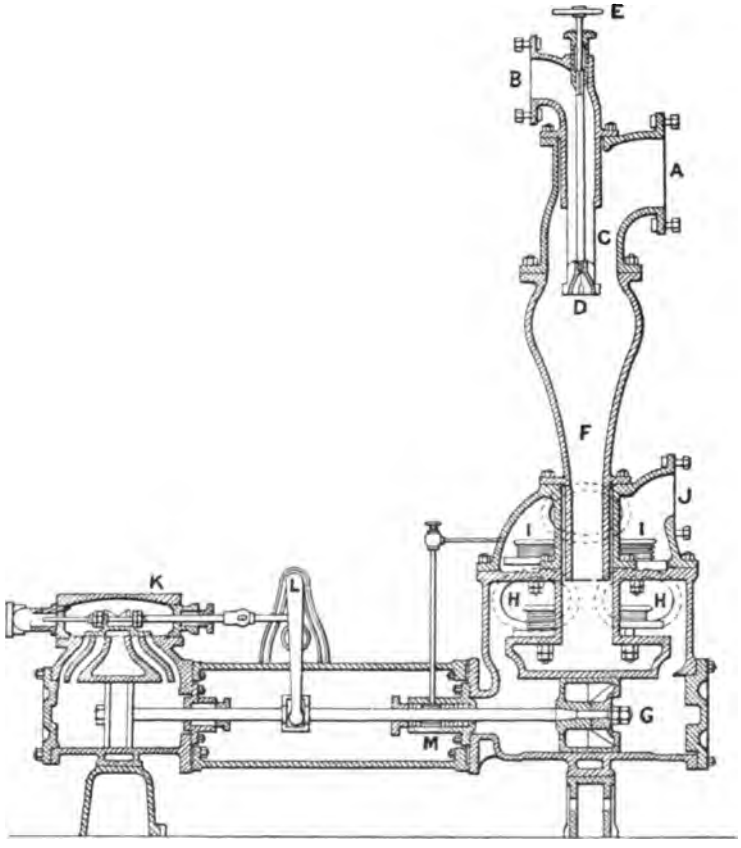


FIG. 128.—Worthington Independent Jet Condenser. Sectional view.

may be said that in all forms of jet condensers operated by air-pumps the injection water and the water from the steam fall to the bottom of the condensing chamber, come to a rest before entering the pump, and consequently lose the value of the momentum acquired when entering the vacuous space. In the Worthington Condenser, however, the construction and arrangement are such that the momentum of the steam and water is conserved, and this force is utilised to assist the pump in its work.'

'In the Worthington Condenser the air set free by the condensation of the steam is intermingled with the water. The pump has the same regularity of motion that is characteristic of Worthington pumping machinery; in fact, it acts as a water pump, although the water is aërated. There is here a great distinction between the Worthington Condenser pumping *aërated water*, and an air-pump pumping *air* and *water* unmixed. In the latter case the air-pump has a varying and irregular duty to perform, and the inevitable result is an irregular and slamming movement.'

The surface condenser consists of a chamber with tube plates at each end into which are inserted tubes, usually of brass, of a small diameter. The water is forced into the condenser and through the tubes by the circulating pump, the steam passes around the outside of the tubes, where it is condensed and removed by the air-pump, which also draws off the air which, if allowed to accumulate, would gradually destroy the vacuum.

For an underground engine, the jet condenser will generally be found to be the more suitable form of condensing apparatus, being both convenient of application and effective in use. It requires less room than a surface condenser, and is practically as efficient. When operated by the main engine, it only entails an extension of the bed-plate. The independent jet condenser is very useful where space will admit of its use, as after the engine has been idle for any purpose the air-pump can be set to work and get a good vacuum ready for the main engine.

Duty.

It is much to be regretted that so little information concerning the performance of these machines in practice is obtainable. And the same remark applies to the cost of engines, indeed, to all the factors essential to a fair and reliable statement of the relative economy of the different forms of pumping engines—their first cost, duty, and durability. The managers and engineers of mines in which these machines are at work—persons who of all others ought to be interested and concerned in the matter—are averse, as a rule, even in those cases where the needful data could easily be supplied, to giving any account of their engines such as would be required for comparing their economic values with other machines, and so promote the adoption of the most efficient. There appears to be generally a lack of interest in this important question, one of the most important connected with pumping machinery; and as long as persons who have engines at work upon their premises, under a variety of circumstances and for a lengthy period, remain indifferent to the manner in which those engines get through their work, and the return they make for their purchase and cost of maintenance, so long will there be conflicting opinions, unsettled views, and undetermined judgments with regard to their comparative worth. We have now little or nothing more to aid us in setting forth the duties of these engines than the remarks which manufacturers have made concerning their own machinery, desultory discussions

of engineers at meetings of scientific societies, and what may be assumed from the construction and principle of the machines.

It is sometimes very difficult to arrive at a knowledge of the duty of these engines, owing to their being worked either by old worn-out boilers, or by boilers which also supply steam to other engines. This we admit, but there are so many instances where the test can be made, and others where a comparatively trifling expense would provide the engine with an independent supply of steam, that it would be very easy to make tests of all the types of machines in use. The interest taken by the owners of the Woodpark Colliery, Bardsley, in their pumping plant and the careful trial they have made of its efficiency are an honourable exception to the rule. In this instance the hauling engines, which were steamed by the same boilers as the pumping engine, were stopped for the purpose of the trial.

The only true test of economy is the expense not only of fuel and stores, but of accidents, and all repairs for a lengthy period. The performance of a machine for a short period cannot be deemed a satisfactory or reliable test of its efficiency, as it might for a short time do a high ratio of duty that would ultimately break it down, or at least so injure it as to require expensive repairs. A few hours' or even days' experiment is not a sufficient trial of the capabilities of an engine, as one that would do a low ratio of duty might really be a more economical machine than one that would do a higher duty, if in the one case we have a steady and continuous performance of work, and in the other frequent breakages or derangements, involving loss of time and money to repair. That engine is the most economical that will do the most work for the longest period and with the least fuel and wear and tear.

It will be appropriate to consider, before proceeding further, the conditions necessary to economy, and then to observe to what extent those conditions exist in the class of engines under consideration.

1. A small expenditure of fuel and lubricants in proportion to the work performed is undoubtedly the first and chief step towards economy in working results. The use of high-pressure steam at a high ratio of expansion is the principal means of obtaining economy in this direction; therefore, all other conditions being equal, that engine is the most economical that affords the greatest facility for great initial pressures and high degrees of expansion.

2. The next condition necessary to economy is durability. A temporary high ratio of duty will not make an engine an economical one in the broad sense we have indicated; there must be a long-continued performance of a fair duty, and the engine must be made of such good materials and be so constructed as to remain in a good workable state for a considerable period.

3. The third condition is that the cost of manufacture shall bear a favourable relation to the effective power of the engine, its working results, and its durability.

Recapitulating, we have as the three conditions necessary to economy: A high ratio of duty. Durability. Small first cost.

The engine, then, that will do the highest duty, or, what comes to the same thing, provides for the greatest expansive use of high-pressure steam, that costs least to keep in working order, that will remain in a good workable state for the longest period, and that costs least to manufacture, is the most economical. But it happens that all these qualities are not found in one machine, and in order to determine the relative economical values of machines it will be necessary to discover to what extent they severally combine these conditions.

The compound engine [1] will admit of being worked under degrees of expansion that would be quite impracticable, without a considerable moving mass and a very high initial pressure and speed, in a single-cylinder engine. A high pressure of steam, high degrees of expansion, and considerable piston speeds (which are conducive to economy) are attainable without either a high maximum piston speed, a heavy initial strain, or a very large moving mass. It is claimed for the compound engine that at an expansion of ten times it produces less variation than a single-cylinder engine cutting off at 40 per cent. of the stroke.

The following summary table has been prepared showing the most economical results of performance of single-cylinder and compound-cylinder steam-engines under various conditions. These results are not put forward as final, but simply to indicate the directions in which the best action of the steam-engine may be obtained: [2]

Description of cylinders	Most efficient ratio of expansion	Steam, or water from the boiler, consumed per I.H.P. per hour
	Initial volume = 1	lbs.
Single cylinder, with steam-jacket, condensing:—		
Thoroughly steam-jacketed { Long stroke	4	21
Thoroughly steam-jacketed { Short stroke	6	20·6
Only side-jacketed { Long stroke	3·2	21·7
Only side-jacketed { Short stroke	5	23
Single cylinder, with steam-jacket, non-condensing	4	25
Single cylinder, without jacket, condensing:—		
{ Long stroke	4·5	20
{ Short stroke	4·25	25
Single cylinder, without jacket, condensing, steam superheated	4	15·5
Single cylinder, without jacket, non-condensing, cylinder well protected	4	18·5
Compound cylinder, steam-jacketed, condensing:—		
Receiver	10	15–16
Woolf	12	14–18
Compound cylinder, no jackets, condensing:—		
Receiver	6·5	23
Woolf	9·5	21

[1] We are not referring to the compound engine used underground.

[2] D. K. Clark, M.I.C.E. *Rules, Tables, and Data for Mechanical Engineers*, p. 890.

The accompanying table[1] contains a comparison of the initial, terminal, and average pressures, maximum piston speeds, and proportions of weight of mass to the water-load :—

	Type of engine	Pressures: Initial absol'te	Pressures: Terminal absolute	Pressures: Average	Pressures: Initial + terminal	Pressures: Aver'ge + terminal	Forces: Initial + mean	Piston velocities: Max. velocities per minute	Piston velocities: Mean water speed per min.	Mass + water load
		lbs.	lbs.	lbs.	lbs.	lbs.		ft.	ft.	
a	Cornish	45	10	19	4·5	1·9	2·26	500	80	3 abt.
b	Ditto .	31	10	16·1	3·1	1·6	1·8	600	—	1·7
c	Ditto .	25	9	12·2	2·77	1·35	1·72	600	—	1·7
d	Compd. differential .	80	10	24·1	10·66	2·4	1·37	220	150	2
e	Ditto .	43·7	7	12·75	6·24	1·8	1·4	228	168	0·66
f	Ditto .	85	11·3	20·25	7·5	1·78	1·3	—	—	1·1
g	Ditto .	25	8·5	14	—	1·6	—	210	144	1·2
h	Single cylinder differential .	30	17	19·6	1·75	1·15	1·4	190	130	1·1
i	Corliss .	45	6	16·97	7·5	2·8	2·53	—	—	—
j	Cornish .	—	—	13 about	—	—	—	600	100	1·7
k	Ditto .	—	—	—	—	—	—	570	112	1·7

The foregoing shows how easily high-pressure steam and great degrees of expansion can be used in compound direct-acting engines without a high maximum piston speed or a large moving mass, both of which are necessary in the single-cylinder engine. The highest initial pressure in the Cornish engine is in the case of an engine (*a*) having a mass equal to three times the water-load. The initial pressure is not more than 45 lbs. per square inch. In the compound engine (*d*) the initial pressure is 80 lbs. and the mass is only twice the water-load. The terminal pressure is the same in both cases. From what has been stated of the facility with which expansion can be carried out in a compound engine, and the high ratios of the expansion, we shall be prepared to learn that this engine is capable of performing a high duty.

The valuable information on the next page, relative to the economy and efficiency of various classes of steam-engines, is extracted from 'Steam-Engine Economy of Condensing Engines,' by Mr. Henry Davey, M. Inst. C.E.[2] The list appears to comprise only engines for water-works and marine purposes. J and N indicate jacketed and non-jacketed respectively.

Mr. Bramwell, in a paper on the 'Economy of Fuel in Steam Navigation,'[3] supplied a table of nineteen engines which had an average consump-

[1] *Proceedings of Inst. Mechanical Engineers*, 1872, p. 125.

[2] *Proceedings of Inst. Civil Engineers*, vol. cxxii., session 1894–5, part iv. (Quoted by permission.)

[3] *Proceedings of Inst. Mechanical Engineers*, 1872, p. 125.

STEAM-ENGINE TRIALS.

Type of engine	Reference No. of trial	Initial pressure	Average pressure	Ratio of Expansion	Lbs. of steam per I.H.P. per hour	Engine-efficiency $\frac{p}{P}$	Units of work per unit of heat
						Per cent.	
Cornish . . .	2	31 J	15·70	2·83	24·00	71·3	68·7
,, . . .	52	27 J	—	3·12	21·38	78·8	80·1
,, . . .	55	34·25 J	14·80	3·87	20·72	71·1	76·9
,, . . .	53	40 J	—	4·17	20·08	72·0	84·8
,, . . .	54	36 J	—	4·28	18·82	76·0	90·6
Averages .	—	33·65	15·20	3·65	21·00	73·8	80·2
Single-cylinder rotative	1	34 J	17·46	2·63	26·69	69·8	65·0
,, ,, ,,	1*a*	36 N	17·13	2·34	32·14	60·8	53·8
,, ,, ,,	60	105·79 N	37·00	4·76	20·37	67·0	85·7
,, ,, ,,	58	104·77 N	36·40	4·93	19·15	65·9	89·03
,, ,, ,,	59	102·79 N	34·50	5·13	19·22	69·0	88·7
Averages .	—	76·67	28·49	3·95	23·51	66·5	76·44
Marine compound .	3	77·5	24·80	4·96	21·73	64·4	78·11
,, ,, .	4	66·5	19·90	5·33	21·17	61·0	78·8
,, ,, .	5	108·0	30·17	5·71	20·77	60·1	81·0
Three-cylinder compd.	6	91 J	28·19	6·06	18·11	68·7	93·5
,, ,, ,, .	6*a*	91 N	27·08	5·98	19·15	66·0	71·7
Rotative ,, .	7	78 J	22·23	6·36	19·52	65·4	90·0
,, ,, .	7*a*	75 N	22·04	5·62	21·06	62·6	88·8
Non rotative ,, .	57	72·2 J	15·13	9·17	17·70	63·0	96·8
Rotative ,, .	8	102 J	22·07	9·48	15·90	66·0	106·1
,, ,, .	8*a*	99 N	21·28	8·61	17·67	60·2	95·5
,, Beam ,, .	10	60 J	12·45	10·08	16·64	66·0	102·1
,, ,, ,, .	10*a*	64 N	12·80	9·5	18·20	62·1	92·8
,, ,, ,, .	56	109·2 J	21·78	10·16	16·24	64·0	103·6
Horizontal non-rotative compound .	11	87·0 J	17·00	11·3	15·6	65·4	110·8
Averages .	—	84·3	21·20	7·73	18·53	63·9	92·11
Rotative triple-expansion	9	127 J	27·36	10·07	15·370	68·4	108·80
,, ,,	9*a*	129·5 N	26·37	9·54	17·170	61·3	97·60
Marine ,,	12	137·5	19·86	11·60	19·830	50·7	84·84
,, ,,	13	154·0	30·30	11·60	14·970	68·2	111·00
Land ,,	14	161 N	30·07	14·18	12·510	76·2	136·08
Pumping ,,	15	128·5 J	19·18	15·30	14·240	63·9	117·40
,, ,,	15*a*	126 N	19·22	14·40	14·690	64·0	113·80
,, ,,	16	132·7	21·57	16·14	12·155	72·6	137·30
,, ,,	17	127·5 J	19·24	16·30	13·160	69·2	127·80
,, ,,	17*a*	126·5 N	19·39	15·60	13·470	67·8	124·10
Marine ,,	19	164·5	21·13	18·90	13·350	62·9	125·10
Pumping ,,	18	142 J	16·30	18·53	15·450	59·5	108·20
,, ,,	18*a*	142 N	16·46	16·50	17·220	53·4	97·20
Averages .	—	138·3	22·03	14·51	14·880	64·4	114·55

tion in long sea voyages of 2·11 lbs. of coal per indicated horse-power per hour, while five of the engines consumed less than 2 lbs. of coal. The

absolute boiler pressure ranged from 63 to 75 lbs. per square inch, and appears to have been admitted to the high-pressure pistons at nearly the same pressure. Marine compound engines do not now consume more than from about 1¾ to 2 lbs. per I.H.P. per hour. Triple-expansion engines achieve a still higher duty, say 1·4 to 1·6 lbs.; under the best conditions, using 200 lbs. pressure steam, they give 1 I.H.P. per hour for 1 lb. of good coal.[1] In the case of marine engines we have the compound engine placed under the most favourable circumstances for a high duty, and their performances may be taken as the utmost useful effect obtainable from compound engines. The boilers and the engines are in proximity, and the latter are brought direct to the work, and can be run at a very great speed. In the types of compound 'differential' pumping engines of Mr. Henry Davey, which are worked at the surface, and supplied with steam from boilers alongside, a high ratio of duty can also be performed; *e.g.*, an engine of the Croydon type at a colliery, with boilers not roofed over, and the steam jacketing far from perfect, consumed 22 lbs. of water per I.H.P. per hour, equal to about 2·3 lbs. of coal, or about 70,000,000 duty, the steam pressure being 80 lbs. (absolute) per square inch.

As the type of engine now under consideration is applied direct to the water by placing it underground, we have to consider the duty it will under such a circumstance perform. When an engine is placed down a deep pit one of two alternatives must be adopted. The steam must be conveyed to the engine from the surface, or it must be supplied from a boiler placed underground near the engine. The former method is most generally adopted. It is awkward to have a boiler underground for reasons that have been already stated.

The Davey Compound Differential Engine erected at the bottom of the Woodpark Colliery, Bardsley, about six years ago, is supplied with steam (at 80 lbs. pressure) by two Cornish boilers fixed underground near the upcast shaft, and about fifty yards from the engine. Full particulars of this engine and the interesting trial made will be found at page 203.

Assuming the marine compound engine to perform a duty of 2 lbs. of coal per indicated horse-power per hour, and bearing in mind that much of that high duty is due to the high pressure of the steam, the very great rapidity (say from 500 to 700 feet per minute) with which the piston is driven, and the proximity of the boiler to the engine, we have, in the case of the compound engine used underground for pumping, and supplied with steam from the surface, to make three allowances:

1st, for a diminished piston speed, say about one-third of that of the

[1] A new Worthington Vertical Triple Expansion Engine, with the 'high-duty attachment,' at the West Middlesex Water-works, Hampton, according to experiments made by Prof. Unwin, January 23 and 24, 1893, and February 6 following, consumed 17·474 lbs. of steam and 1·619 lb. of coal (after deducting ash) per I.H.P. per hour. A new Worthington Horizontal Compound Engine at the West Middlesex Water-works, Hammersmith, with the 'high duty attachment,' used 1·88 lb. of coal per I.H.P. per hour, as the result of a trial made Nov. 17, 18, 1890, by Mr. Osbert Chadwick.

marine engine, owing to the speed of the steam and water pistons being identical;

2nd, for loss of steam in condensation. It appears from actual results that the loss of steam in condensation under the most favourable circumstances when taken down a deep pit amounts to about ½ lb. of coal per indicated horse-power per hour. Take a case in point. 'A pair of "differential" engines with 20-inch cylinders are supplied with steam from the surface in 7½-inch pipes, clothed with non-conducting cement, of a total length of 1,100 feet. The loss of steam from condensation was found to amount to 8 cubic feet of water per hour when the engines are standing, and 12 cubic feet when working at the ordinary speed of 10 double strokes per minute, with 45 lbs. of steam. . . . The loss of coal from this condensation in the steam-pipe amounts to 2,160 lbs. in 24 hours if the engines are standing half the time, or 2,592 lbs. if working continuously.' This loss is equivalent to about ½ lb. of coal per indicated horse-power.

At Tynewydd Colliery, as has been already stated, the loss in conveying steam 130 yards through a 2½-inch pipe was 8 lbs. per square inch, the steam being supplied at 110 and used at 102 lbs. per square inch.

3rd, for the smaller amount of expansion available owing to the loss of pressure by condensation and friction. In an underground compound engine it is necessary to carry full steam the whole length of the stroke in the high-pressure and to expand it in the low-pressure cylinder. Without a very high initial pressure of steam the moving mass is not sufficient to permit of any expansion in the first cylinder. This practically means that such an engine, taking the areas of the high and low-pressure cylinders as 1 to 6, is only capable of an expansion equivalent to the steam being cut off at one-fifth of the stroke in a single-cylinder engine. The accompanying indicator diagram, fig. 129, shows the expansion in a 22-inch and 54-inch engine. Considering these serious drawbacks, it is doubtful if underground compound engines will yield a better result under ordinary circumstances than 4 lbs. of the best steam-coal per indicated horse power.

Let us now examine to what extent expansion is practicable in a single-cylinder pumping engine, specially the Cornish engine, which may be said to be the universal standard of comparison for pumping engines.

The conditions necessary to expansion are:—

1. *A heavy moving mass*, to absorb the excess of pressure at the beginning of the stroke, like a fly-wheel, and to give it out towards the end of the stroke, to compensate for the diminishing pressure of the steam.

2. *A great initial pressure of steam*, to start the moving mass. The latter in the Cornish engine, consisting of the large main beam, heavy pump-rods, plungers, etc., is in deep mines always very much in excess of the water-load, but an appreciable portion of the weight is taken up by the balance beam (one or more) and the engine correspondingly assisted. The ratio of the moving mass varies according to the depth of the mine, from twice to five or six times the water load, but it is usually perhaps not

more than three times. In one extreme instance it amounted to about 11½ times the water load. The ratio of expansion is in proportion to the excess of the moving mass and the pressure of the steam. If the moving mass were only that sufficient for raising the water, only a moderate degree of expansion could be used. The reader will clearly see that, with a very ponderous, inert mass, a high initial pressure of steam is requisite, not only to start it, but to do so with a sufficient impetus that when the steam is cut off, the momentum and the diminishing force of the steam shall carry it to the end of its stroke. This leads to a very great piston speed at the beginning of the stroke, equivalent in some instances to 800 feet per

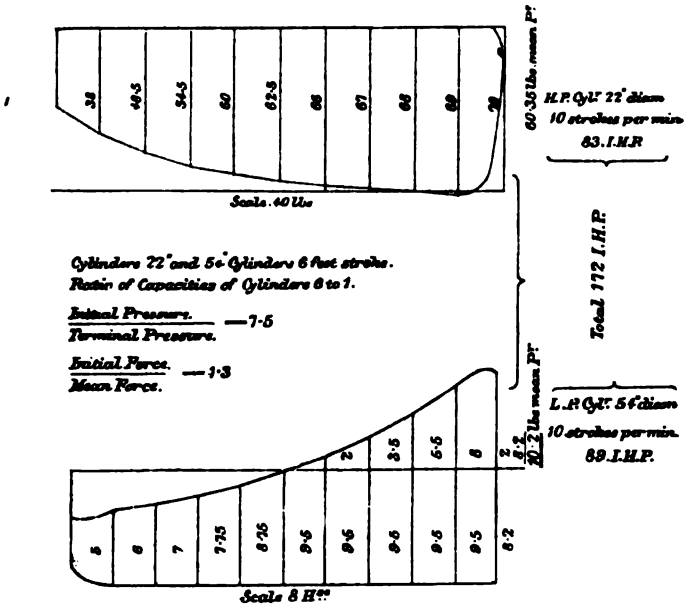


FIG. 129.—Underground Differential Compound Engine.

minute, and a sudden strain and concussion which at high degrees of expansion are injurious to the machinery, and it is for this reason that very high ratios of expansion can seldom be adopted with safety.

When working at its greatest speed the mean velocity of the piston on the steam stroke varies from about 250 to 350 feet per minute, and in some instances it is as much as 600 feet per minute. The steam stroke is usually much faster than that caused by the descent of the rods. The initial speed of the piston is at least double the terminal, and in the case of very high degrees of expansion it may be three times.

Owing to the strain and concussion of the machinery at the beginning

of the stroke, caused by the use of very high-pressure steam, a moderate pressure, compared with that which has been adopted in compound engines, is used in the single-cylinder engine. The pressure usually adopted in a Cornish engine is not above 45 or 50 lbs. per square inch; but higher pressures are sometimes resorted to, such, for instance, as 64 lbs. in the Rio Tinto engine.

The following recapitulation of pressures, speed, etc., shows the greater facility which the compound engine offers for the expansion of steam:

	Cornish engine			Compound 'differential' surface engine	
	1st ex.	2nd ex.	3rd ex.	1st ex.	2nd ex.
Initial steam-pressure (absolute) lbs.	45	31	—	80	43·7
Terminal ditto	10	10	—	10	7
Maximum piston speed . feet	500	600	570	220	228
Mean water speed . . feet	80	—	112	150	168
Proportion of mass to water load .	3 to 1	1·7 to 1	1·7 to 1	2 to 1	·66 to 1

It must be conceded, notwithstanding the above examples, which do not fairly represent its merits, that the Cornish engine admits of the greatest economy in expanding steam. The momentum which can be stored up in the moving mass is sufficient to keep the engine in motion at a lower pressure of steam than is possible in any engine not having such a preponderating inert weight. With a mean water load of 12 lbs. per square inch the steam may be expanded down to from 5 to 3 lbs. Taking this, and the loss of pressure in expanding in two cylinders, into account, it is evident there must be a much higher ratio of expansion in a compound than in a Cornish engine to produce the same useful effect, and steam of a higher pressure is condensed.

'It was about the year 1785 that Watt introduced the principle of the expansion of steam into Cornwall, but the steam was not raised higher than before, and the piston made a considerable part of the stroke, therefore, before the steam-valve was closed.'[1] Great strides were made in this direction after Mr. Watt's death, and high degrees of expansion led to high duties being performed. The highest ratio of expansion has been, we believe, ten times, but it is very rare for such a great expansion to be attempted. The celebrated Taylor's engine, at the United Mines, Gwennap, worked at a cut-off of one tenth of the stroke, and performed the very high duty of 107,500,000 lbs. raised 1 foot high by the combustion of a bushel of coal (94 lbs.).[2] Another Cornish engine—Austen's, at Fowey Consols Mine—as the result of a 24 hours' experiment, did a duty of 125,000,000 lbs., and 90,000,000, and nearly 98,000,000 in two months

[1] Mr. Taylor's *Records of Mining*.

[2] Previous to July 1856 the duty was computed per bushel (94 lbs.) of coal, but since that date it has been computed per cwt. (112 lbs.).—S.M.

for the same quantity of coal. In 1834 the average duty of the best engines for the year was about 91,000,000 lbs. In the following year Austen's engine did an average duty of 91,672,210 lbs.[1] In September 1836 the Wheal Darlington engine performed an average duty of 95,000,000 lbs. for the month. The system of reporting the engines having fallen in a great measure into disuse, and the same care not now being taken to produce great results, and many of the engines being very old, the shafts deeper, and a greater number of them inclined, the average duty is now only about 50,000,000, and the greatest cut-off is about one-fifth of the stroke. Lean's 'Reporter' for Feb. 1871 shows an average duty for the month of nearly 56,000,000, the highest being 79,400,000. The highest duty ever recorded, 125,000,000, for a bushel of coal is equal to a consumption of 1·49 and about 1·12 lbs. of coal per effective and indicated horse-power per hour respectively; 107,500,000 is equal to 1·73 and 1·29 lbs., and 90,000,000, which we believe the engine, under favourable circumstances, is able to do continuously, is equal to 2·06 and 1·55 lbs. per effective and indicated horse-power per hour respectively. Having a due regard, however, to the durability of the engine and the pump-work, it is a wiser economy to work at a moderate grade of expansion, and to realise, say, a duty of 70,000,000 for 112 lbs. of coal, equivalent to 3·17 and 2·40 lbs. of coal per effective and indicated horse-power per hour respectively.[2]

In passing we would remark that a useful constant in reducing duty in millions of pounds lifted one foot by the consumption of a hundredweight of coal to pounds of coal per effective horse-power per hour and *vice versâ* is 222,[3] used thus, taking the above-named duty as an example, $222 \div 70 = 3{\cdot}17$. The constant for indicated horse-power is 168. To reduce to millions of foot-pounds, $222 \div 3{\cdot}17 = 70$.

A careful trial made February 11, 1893, of the Davey Differential Compound Condensing Engine fixed underground at the Woodpark Colliery, Barnsley, and supplied with steam by boilers *underground* near the upcast shaft about 50 yards from the engine, ascertained that the coal used per indicated horse-power per hour was 4·88 lbs. The following is a summary of the trial, which was made by Mr. W. W. Millington (President of the National Association of Colliery Managers), and the colliery engineer and staff, with particulars of size, etc.

[1] This engine is now in the north of England, and is believed to be still at work.—S. M.

[2] 'From an examination of several indicator diagrams of pumping engines, I have come to the conclusion that the difference between the indicated horse-power and the effective varies from 25 to 50 per cent.; therefore, for the sake of comparing the duty performed by different engines, the indicated as well as the effective horse-power should be reported. When comparing the duty performed by pumping engines, and those employed for marine or other purposes, it must be borne in mind that the first is effective and the latter indicated horse-power. Thus, corrected for friction, the consumption of coal per indicated horse-power per hour, when in 1844 the average duty was 68 millions, did not probably exceed 2¼ lbs., a result not surpassed by the average working of the best compound engines of the present day consuming best steam-coals.'—(Mr. W. Husband on 'Pumping Machinery,' *vide Proceedings Mining Institute of Cornwall*, pp. 173–4.)

[3] Thus, $33000 \times 60 \times 112 = 221{,}760{,}000$.

Direct-acting Compound Condensing Engine cylinders	15 ins. and 26 ins. dia.
Differential Rams	5 ins. and 7¼ ins. dia.
Double-acting air-pump	8 ins. dia.
Length of stroke	3 ft.
Two Cornish boilers	5 ft. 6 in. dia. × 18 ft. [long.
Rising main 5 ins. dia. at the bottom to 6½ ins. at top; outside dia. throughout	8 ins.
Duration of test	3½ hours.
Average length of stroke	2 ft. 11½ ins.
,, number of strokes per minute	23½.
Boiler pressure	80 lbs.
Water pumped—calculated from ram displacement	26,040 gallons.
,, ,, as measured by weir	25,200 ,,
,, ,, per minute	120 ,,
Percentage of slip in water pumped	3·6.
Vertical lift	1,341 ft.
Mean I.H.P.	59.
,, pump H.P.	50.
Mechanical efficiency	85 per cent.
Total amount of feed water	750 gallons.
,, ,, feed water per I.H.P. per hour	36·4 lbs.
,, ,, ,, ,, pump H.P.	43.
,, ,, coal consumed	9 cwts.
Water evaporated per lb. of coal	7·44 lbs.
Coal per I.H.P. per hour	4·88 lbs.
Coal per I.H.P. taking 9 lbs. water evaporated per lb. of coal	4 lbs.
Coal per pump H.P. per hour	5·7 lbs.
,, taking 9 lbs. of water evaporated per lb. of coal	4·8.
Temperature of water in hot well	101° to 125° F.
Vacuum	24 ins. to 25½ ins.
Cost of pumping, 3½ hours	6 shillings.
,, ,, 1,000 gallons, 1,341 ft.	2·85 pence.

An Evans Compound Condensing Engine, used underground at the North Elswick Colliery, Newcastle-on-Tyne, with 100 lbs. per square inch steam pressure at the boiler, has done a duty of 3½ lbs. of coal per I.H.P. per hour on a 10 lbs. boiler evaporation. A Compound Duplex Engine by the same makers, supplied to the Mickley Coal Company near Newcastle-on-Tyne, is believed by the makers to do a good duty. They say: 'The duty of this engine is very good, and cannot exceed about 3 lbs. of coal per I.H.P., as one 28 feet × 7 feet 6 inches Lancashire boiler fired easily will supply steam for it.'

Let us take two modern examples of Cornish engines. The information contained in Mr. Nicholas Trestrail's [1] Paper on Cornish pumping engines, and that courteously supplied to the Author, together with diagrams, by Mr. E. Hodge, of the Ookiep Copper Mines, Namaqualand, is of such

[1] Nicholas Trestrail, Assoc. M.Inst. C.E., *The Duty of Cornish Pumping Engines, Past and Present, and as compared with others*; a Paper read before the South Staffordshire and East Worcestershire Institute of Mining Engineers, Dec. 3, 1896. (Excerpt from the *Transactions Federated Inst. Mining Engineers*, by permission.)

interest and value that at the risk of overstepping the limits of this work the same is reproduced here.

'The writer (Mr. Trestrail) was indebted to Mr. Rich, the manager of the Rio Tinto mines, Spain, for furnishing him with a detailed account of a trial of a Cornish pumping engine, a facsimile of one which the writer designed and erected on the Tincroft mines. Of course, the pump arrangement was of a suitable design for their respective requirements. In the calculations, the ashes and clinker, amounting to 3·4 per cent., are not deducted; but if they were, the duty becomes 115,300,000 foot-pounds. There was no feed-heater or economiser. The duty was reckoned on the total vertical height of the pump, and not by a height corresponding to that indicated by a gauge on the pump. The trial was conducted by the officials and engineers on the mine, with the following results:—

'*Dimensions.*—Cylinder, 70 inches in diameter and 10 feet stroke; air-pump, 34 inches in diameter and 4¾ feet stroke; feed-pump, 7 inches in diameter and 2 feet 5½ inches stroke; plunger, 35 inches in diameter and 9 feet stroke (the full stroke between catches being 9 feet 1¾ inches). The four-beat valves had a clear diameter through the seat of 36 inches. Valve-box passages were 36 inches in diameter. The pipes to air-vessel were 35 inches in diameter. Rising-main pipe was 24 inches in diameter, length from top valve to top of column was 441 feet 6 inches, and the vertical height from water-level to top of column was 196 feet. The boilers were 6 feet in diameter, 30 feet long, with tubes 3¾ feet in diameter, fitted with eight Galloway tubes; the fire-bars were 5½ feet long, and the grate-area was 21·1 square feet.

'The following are the results of a trial made from October 27 to November 3, 1894:—

Time of trial	168 hours.
Time actually working	167 hours 52 minutes.
Number of strokes	102,279.
Coal consumed	78,484·5 lbs.
Feed-water pumped	830,561·2 lbs.
Specific gravity of water	1·0466.
Steam pressure, mean of gauges on boiler	64 lbs. per square inch.
Vacuum gauge, mean	27·82 lbs. per square inch.
Temperature of injection water	67 degs. Fahr.
Temperature of hot well	112 degs. Fahr.
Temperature of feed-water	109 degs. Fahr.
Ashes and clinker, not deducted	2,712 lbs.
Mean strokes per minute	10·154.
Volume of water pumped per hour	1,027·0515 cubic metres.
Total work per stroke	761,461·4275 foot-pounds.
Total work during trial	77,881,513,343 foot-pounds.
Full capacity of stroke	103,907·88 cubic inches.
Net capacity of stroke, after deducting 1 per cent. of slip	102,868·8012 cubic inches.
Volume of 1 lb. of water (standard)	27·7123 cubic inches.

Weight of water lifted per stroke	3.885·0073 lbs.
Volume of cubic metre	61,027·0515 cubic inches.
Total volume lifted during trial	172,404·17 cubic metres.
Effective horse-power	234·317 horse-power.
Duty per cwt. of coal	111,139,518 foot-pounds.
Work per stroke, mean of 8 cards	941,375·5097 foot-pounds.
Total work during trial	96,282,943,756·606 foot-pnds.
Total work during trial	289·658 horse-power.
Mechanical efficiency	80·88 per cent.
Coal burnt per hour	467·559 lbs.
Coal burnt per hour, per indicated horse-power	1·6141 lbs.
Coal burnt per hour, per effective horse-power	1·9954 lbs.
Feed-water evaporated per hour	4,947·91 lbs.
Feed-water evaporated per hour, per indicated h.p.	17·082 lbs.
Feed-water evaporated per hour, per effective h.p.	21·112 lbs.
Feed-water evaporated per lb. of coal	10·582 lbs.

'From a diagram taken during the trial, the writer finds that the steam was cut off at slightly over one-fifth from the commencement of stroke, and reviewing the results of this trial with those already referred to, it is plain that this engine did most efficient duty.'

The following reduced copy, fig. 130, of the diagram referred to is inserted by the kind permission of Mr. W. Rich, the manager.

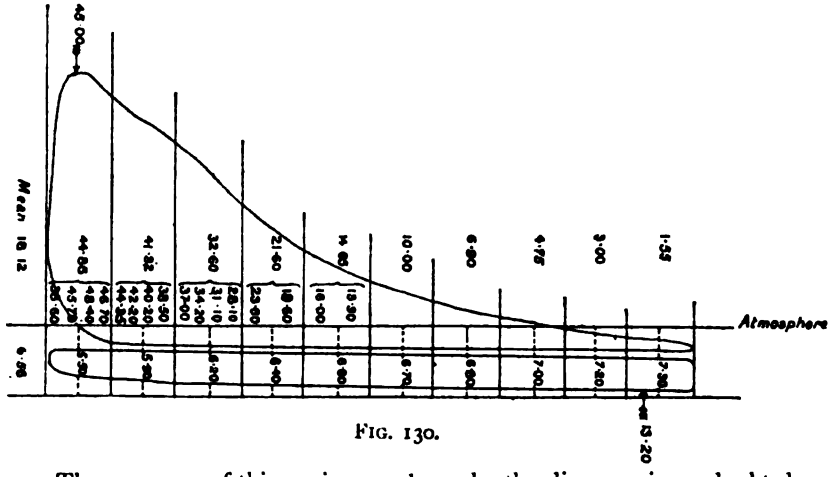


FIG. 130.

The economy of this engine, as shown by the diagram, is no doubt due largely to the high ratio of expansion. Although the steam-valve probably did not close until $\frac{1}{5}$th of the stroke, the expansion commenced much earlier, due to 'wire-drawing.' It is a splendid diagram: doubtless the shallow mine favours the economy.

Mr. Hodge writes:[1] 'Our pumping engine was made by Harvey & Co., and started in December 1883. It has a 50-in. cylinder, 9-feet and 8-feet stroke; is designed to work either single or double-acting, but the latter will never be required. We have a wrought-iron main beam, one strong balance

[1] Letter to the Author, dated July 26, 1897.

beam at surface drawing flat rods from the King Post between the K limbs. There are two Cornish boilers 30 ft. × 6 ft., with Galloway tubes, one boiler only used at a time. We have a Green's Economiser which raises the feed water to about 170° Fahr.

'The engine is one of Harvey's, therefore of the first class. We have excellent Welsh coal (Ocean Merthyr). The engine is maintained in prime order. We have skilled stokers and English drivers; logs are taken morning and evening; diagrams occasionally. I know of nothing that can be done by the engineers to improve the duty, which compares favourably with the Cornish average, but cuts a sorry figure compared with the instances of Fowey Consols, United Mines, and Rio Tinto. Our duty varies between 60 and 65 millions, but we have to contend with some adverse circumstances beyond the engineers' control. We have a large number of small lifts. We pump mine water from ore ground, and drink water from quartz, in separate lifts, simultaneously. Then we are saddled with the engineers' curse, flat rods, attached to a 20-in. and a 15-in. plunger, 363 yards from the engine.

'Either or both of these pumps, as required, work by day only. Under these circumstances possibly a duty of from 60 to 65 millions is not discreditable. The shaft is 130 fathoms from brace (depth). The mine water is raised to about 30 feet, and the drink water about 70 feet above brace.

Details of Pit Work.

'122 fathoms (in three lifts) of 8-inch plunger lifts, 8-feet stroke, from 117 fathom level to height of mine reservoir.

'16$\frac{5}{8}$ fathoms of 7-inch drawing lift, 8-feet stroke, from 130-fathom fork to 117 fathom level.

'130$\frac{2}{3}$ fathoms (in four lifts) of 3$\frac{3}{4}$ inches plunger lifts, from 117 fathom level to high service reservoir. Domestic purposes water.

'3$\frac{1}{6}$ fathoms of 14-inch plunger lift, 3$\frac{1}{4}$-feet stroke, house water lift from engine to mine reservoir.

'8 fathoms of 20-inch plunger lifts, 9-feet stroke.

'8 fathoms of 15-inch plunger lifts, 9-feet stroke.

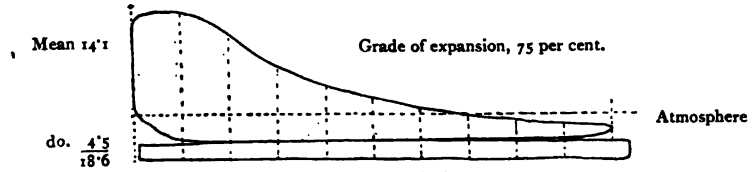
'The two latter are Floor's repeating pumps, drawn by round iron 'flat rods,' at 363 yards from engine.

'I see by my diagram book and notes, a duty of 68 millions recorded in August 1892, but I regard this as exceptional, and select in preference diagrams (enclosed) and statistics for October 1893, as a fair average month, *just precisely what we are doing now.* Our water rate has during several dry years fallen from 5 to 3·8 strokes per minute. We have practically the same speed in summer and winter, as our rainfall averages only seven inches, while for the last two years it has been less than 4 *inches per year.* The three enclosed diagrams[1] give the heavy, medium, and light load, viz.:—

a. 1st, all shaft lifts, with 20 in. repeating lift.
b. 2nd ,, ,, ,, 15 in. ,,
c. 3rd ,, ,, ,, 10 in. ,, Night work.

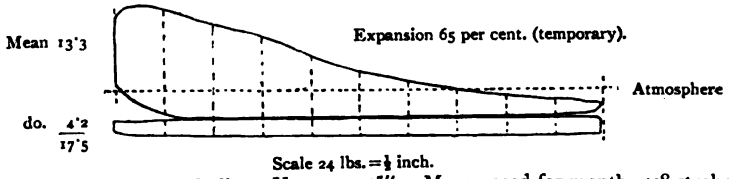
[1] The diagrams given are reduced from those supplied by Mr Hodge.—S.M.

October 31, 1893. 50″ Pumping Engine. 9 ft. stroke in cylinder. 8 ft. stroke in shaft



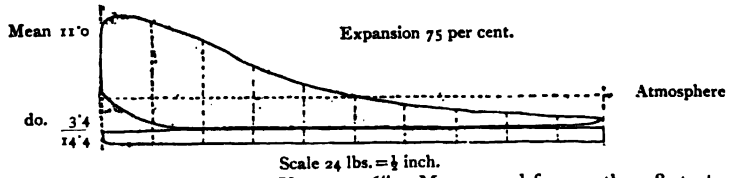
A. Pressure at engine 55 lbs. Vacuum 26″. Mean speed for month, 4·8 strokes per min. Indicated power, 47·8 H.P.

FIG. 131.



B. Pressure at engine 60 lbs. Vacuum 25⅞″. Mean speed for month, 4·8 strokes. Indicated power, 45 H.P.

FIG. 132.



C. Pressure at engine 60 lbs. Vacuum 26″. Mean speed for month, 4·8 strokes. Indicated power, 37 H.P.

FIG. 133.

Statistics.

Diagram *a*, full load with 20 in. surface pole connected . . 48·7 I.H.P.
,, *b*, intermediate load with 15 in. surface pole connected 45·0 I.H.P.
,, *c*, light ,, with no ,, ,, 37·0 I.H.P.

Full	48·7 × 100 hours		4,870
Intermediate	45·0 × 183	,,	8,235
Light	37·0 × 461	,,	17,057
	744		)30,162(40·54

Mean indicated power for month	40·54 I.H.P.
Pounds of water raised 1 foot during month . . .	40,958,483,001 lbs.
Coal consumed	33 tons 3 cwt.
Duty. Million lbs. raised 1 ft. by 112 lbs. coal . .	61·8 mills.
Consumption per mean I.H.P. per hour	2·46 lbs.
,, ,, sq. ft. of grate	6·00 lbs.
Vacuum—3,000 ft. above sea level	26 ins.
Effective H.P. 33,000 ft. lbs. actual	27·8 H.P.
Percentage of friction, flat rods, &c.	31·4 per cent.
Expansion, with one temporary exception . . .	75 per cent.

'*Note.*—75 per cent. is by measurement on plug rod. By diagrams this actually amounts to about 80 per cent., as much as we dared do with long run of flat rods :—

Feed-water raised by economiser to about	170° Fahr.
Cylinder warmed by steam case, or jacket	
Speed of engine—mean of October, 1893	4·8 strokes.
The effective speed of piston per minute is	43·2 feet.

The duty naturally falls as the speed decreases, radiation, etc. The load being light, 'wire-drawing' is unavoidable. If one large lift in the shaft could be substituted for the present small ones, the flat-rod lift discarded, and the speed doubled, probably a duty of 75 millions might be obtained, a figure hopelessly below the three examples quoted.'

It has become the practice of engineers in the last few years to express duty performance in terms of pounds of steam used per indicated horse-power per hour (in other words, the quantity of feed-water), as well as the coal consumed. There is a great advantage in this, inasmuch as it bases the efficiency of an engine not upon the quantity of coal used, which may be of any quality—good, bad, or indifferent—but upon the actual quantity of steam supplied to it, with which only in any statements of efficiency and economy it should be chargeable. It is manifest that comparisons of engines based upon the quantity of coal used may be very unreliable and misleading unless we also know in each case the precise description of the coal, its evaporative qualities, expressed in pounds of water vaporised per hour, and all the conditions under which combustion is effected. In considering the duty performances of a number of engines there would perhaps not be two examples in which the conditions would be coincident.

To obtain a fair estimate of the merits of an engine, and to compare it with other engines, the engine-efficiency and the boiler-efficiency must be shown separately. A badly designed and badly stoked boiler will spoil the 'duty' of the best engine in the world, if that were only shown by the quantity of coal consumed. Duty shown in pounds of steam may be reduced to pounds of coal by dividing by 10, or, to be nearer the average working result, by 9, the pounds of water evaporated by one pound of coal.

It is too much the fashion at the present time to limit trials of engines to a few hours or perhaps days, and under perfectly artificial and unnatural circumstances, the scientific engineer, whose salary runs into many hundreds a year, taking the place for the few hours of the homely mechanic; the stoking is done by experts, the highest quality of coal is selected, the most extraordinary precautions are taken, and the result is published as the duty, the efficiency, or the economy, or whatever else it may be called, of the engine. It would be just as logical to put an athlete into training, and then on a certain day, specially attired, let him run a quarter-mile race, and regard the result as the man's efficiency and endurance. It would be a better index

to his speed and staying powers to put him to a whole year's trot day by day, in his ordinary garb, and note not only the extent of ground covered, but his condition at the end of it. The Derby race-horse that covers his mile in two minutes with great *éclat* would perchance drop dead before the end of a second or third mile.

Comparing the duty of the Compound Engine used *underground and steamed from surface*, as far as we can ascertain it, with the Cornish Engine, as a good example of an economical *surface* engine, we have approximately—

Compound engine	.	.	5 lbs. of coal per indicated horse-power per hour.
Cornish engine	.	.	2·40 ,, ,, ,,

Compound rotative engines achieve very excellent results. Engines of this kind are said to have attained the very high duty of 111,350,000, or equal to about 2 lbs. per horse-power per hour of effective, or 1·61 lbs. of indicated duty. They seem to be admirably adapted for water-works, but they are not considered to be suitable for deep mine drainage. When working at a low speed a slow motion is given to the pumps compared with the brisk stroke of the Cornish and some other engines working at the same number of strokes per minute. A large slip through the valves results, and the quantity of water actually lifted is much less in proportion to the theoretical quantity than in other machines.

Durability.

It scarcely need be observed that the extent to which a machine is durable is a very important consideration, and one which ought to be carefully taken into account in a comparison of the ultimate values of engines. An engine which may perform a very satisfactory duty in a few hours' or days' trial may yet in its construction contain a weakness, inherent perhaps to the class of engines to which it may belong, and which from the principle of its action it may be impossible to avoid. In mining it is often the case that time is money; night and day there is much 'dead' cost going on whether mineral be obtained or not. In Cornish and other metalliferous mines the bottom workings are often the most valuable, and they can be operated upon only when the pumping engine is at work keeping them drained. A derangement, then, of the pumping apparatus leads to the water filling the bottom of the mine and suspending all work in that part, and the evil will be in proportion to the length and frequency of the stoppages of the engine. A protracted stoppage in a heavily watered mine often leads to serious results; not unseldom is it the cause of a train of other misfortunes, besides the flooding of the mineral veins, such as the running together of ill-secured levels, when the stuff is of a loose nature, the choking-up of adits, etc. It will thus be seen how important it is that the pumping arrangement be of a durable character and little liable to

derangement, and not requiring frequent stoppages for repairs and renewals of worn parts.

The lasting qualities of no engine have been so thoroughly tested as that of the Cornish, the durable nature of which is so well known. A few years ago, when most of the Cornish mines were working, engines could be seen that had been constantly at work for thirty, forty, and even fifty years. The well-known Taylor's engine (85-inch), erected in 1840, was kept almost constantly at work till 1870, and in July of the preceding year it did a duty of 68,750,000 (speed seven strokes per minute, cut-off one-fourth, load 103,200 lbs., or about 15 lbs. per square inch of the piston), thus showing clearly the durable character of the Cornish engine.[1] In 1843 this engine did a very high duty, averaging 99,000,000 foot-pounds for the year, the highest month being 105,000,000, and through the years from 1841 to 1844 inclusive it did splendid work, averaging 97,500,000 lbs. After thirty years' wear and tear, the hard usage of a Cornish mine, and such care and attention as might be expected from enginemen paid a wage of from 70*s.* to 80*s.* per month, to be still at work up to the time the mines were abandoned is a record such as no other class of engine can show. The United Mines were abandoned in 1870, or the durable quality of the engine might have been further exemplified. Another famous engine—Austen's, of Fowey Consols—which in 1834 was reported to do such a high duty, is believed to be still at work in the north of England. The engine which did such good work at Mellanear mine was fifty years old when operations were discontinued. 'With ordinary care a Cornish Pumping Engine will keep in good working order for half a century.'[2]

In underground engines there is more wear and tear in the moving parts and cylinders, particularly when horizontal, than in surface-engines with longer strokes and a slower speed. Underground engines and pumps, being much smaller than surface engines and the pumps connected with them, must run at a much higher speed to get through the same amount of work, and the stroke being shorter a greater number of strokes is necessary. This leads to the valves of both the engine and the pump being operated a greater number of times, and causes considerably more wear and tear. This is one reason why long-stroke should be preferred to short-stroke engines. Some of the movements of the valves of certain steam-pumps are so delicate that a slight obstruction will suffice to prevent their moving at all. This could not be possible in the Cornish engine, as all the movements of the valve-gear are the result of the action of tappets and levers receiving their motion through plug-rods, actuated by the main beam, and, consequently, the great power exerted quite overcomes any obstruction. The gear is, moreover, completely under the control of the engineer.

Valves actuated by tappets are more reliable in their action than steam-moved valves, although they may present more wearing surfaces. If in the

[1] *Engineer*, vol. xxix., p. 325.
[2] *Bickle's Reference Notes for Engineers*, p. 87.

steam-valves of Cornish engines a leakage should be caused by any means, they can easily be again ground true and thus be kept perfectly steam-tight. Under favourable circumstances the valve-gear of these engines may be in use for many years without needing renewing or even repairing; there are no delicate parts, whereas that of many of the steam-pumps is nothing but an assemblage of delicate parts, easily injured or disabled. Steam-pumps being necessarily much smaller than surface engines, the moving parts are of course correspondingly smaller, and therefore more delicate; in addition to this, the nature of their construction renders them more susceptible to derangement.

Let us regard for a moment the durability of the water-end of these pumps. A piston-pump should only be used when the purity of the water and its freedom from solid impurities can be relied upon, as the wear of the cylinder and piston when mud, coal dross, gravel, sand, or any other solid matter is present is very great, and forms a fatal objection to the permanent use of this kind of pump for such water. The nature of the pumping which has to be performed by the Cornish engine in a progressive mine would very soon disable such a pump. As we have already stated, it promotes the durability of the water part of the machine to employ a ram or plunger instead of a piston; the ram works through the unctuous and soft yet water-tight material of stuffing-boxes, and nowhere touches the cylinder. In sinking operations other evils than those named are due to water charged with solid matter. The water-ports are liable to be choked with large substances, as pieces of broken rock, or coal, and wood. The corners around and near the valves are sometimes filled with mud and other solid substances, and the valves prevented from acting properly owing to these substances getting around the seats and between them and the valves. Of course these mishaps occur more particularly to small pumps.

1. COMPOUND STEAM-CYLINDER, EXPANSIVE, CONDENSING ENGINES, WORKING DOUBLE-ACTING PISTON-PUMP.

Shanks's Compound Piston-Pump.

This, as well as all the other pumps illustrated, is a tandem arrangement and belongs to the class shown in diagram (*a*) (fig. 126). The illustration (fig. 134) does not show a condenser. Makers, Messrs. Alexander Shanks & Son, Ltd., Arbroath, Scotland.

The 'Davidson' Compound Piston-Pump.

Fig 135 is an elevation of this engine which needs little explanation. It will be observed it is of the type shown in diagram (*c*) (fig. 126), the centre-line arrangement of piston-rods. The steam and water-cylinders are connected and held together by two distance-bars, as shown, one over and the other under the piston-rods. A condenser is not shown.

The 'Cornish' Compound Piston-Pump.

In this pattern the pump is of the double-acting bucket type, with leather or hydroderma packings, and fitted with Evans's patent rotative disc valves, and the advantages of compounding are attained in a very simple way, inasmuch as one steam-cylinder, one steam-chest, and one slide-valve only are employed, thus avoiding the loss of steam which attends the use of connecting pipes between the cylinders, also in the ports and clearances.

The following are some of the standard sizes suitable for heads up to 300 feet and steam-pressures up to 120 lbs. per square inch. The length of the stroke is twelve inches in each example given.

Dia. of high pressure cyl.	Dia. of low pressure cyl.	Dia. of water cyl.	Water per hour at 100 feet piston speed per minute	Height water raised with 60 lbs. steam	Dia. of suction and deliv. pipes	Dia. of steam pipe	Dia. of exha'st pipe	Length and width	Height to top of air-vessel	Wgt.	Price
in.	in.	in.	gallons	ft.	in.	in.	in.	in.	in.	cwts.	£
14	24	10	20,400	290	8	2½	5	142 × 50	79	80	274
14	24	11	24,680	240	8	2½	5	142 × 50	80	84	282
14	24	12	29,370	200	9	2½	5	143 × 50	91	89	290
14	24	14	39,980	145	10	2½	5	145 × 50	93	96	306
15	26	11	24,680	280	8	3	5½	147 × 55	86	92	332
15	26	12	29,370	235	9	3	5½	148 × 55	98	97	330
15	26	14	39,980	175	10	3	5½	150 × 55	99	104	346
16	28	12	29,370	275	9	3	5½	150 × 57	99	104	367
16	28	14	39,980	200	10	3	5½	152 × 57	100	111	383
18	30	12	29,370	300	9	3½	6	153 × 61	100	110	408
18	30	14	39,980	230	10	3½	6	155 × 61	101	117	424
19	32	14	39,980	265	10	3½	6½	157 × 63	102	124	466

The makers are Messrs. Jos. Evans & Sons, Wolverhampton.

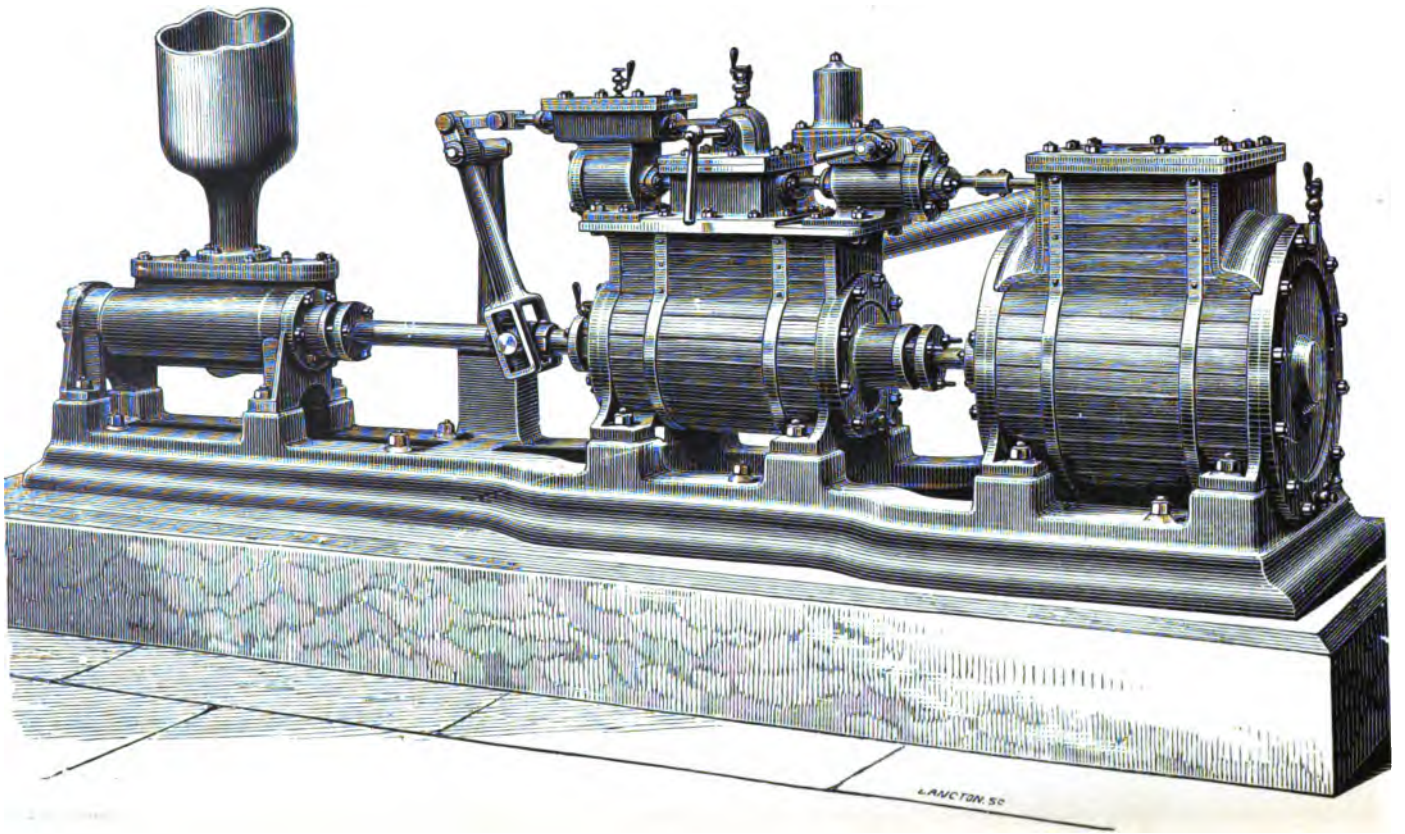


FIG. 134.—Shanks's Compound Piston-Pump.

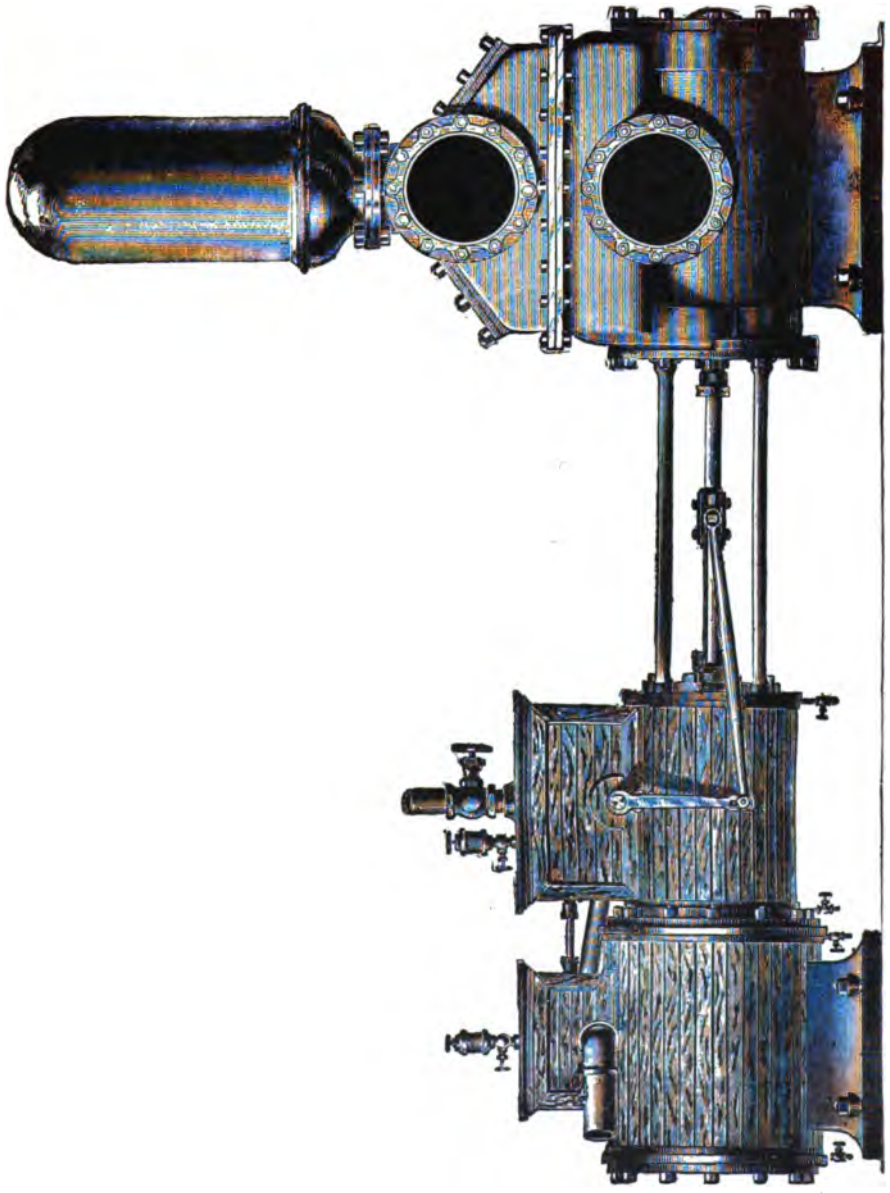


FIG. 135.—The 'Davidson' Compound Piston-Pump.

2. COMPOUND STEAM-CYLINDER, EXPANSIVE, CONDENSING ENGINES, WORKING DOUBLE-ACTING RAM-PUMP.

DAVEY'S 'DIFFERENTIAL' COMPOUND PLUNGER-PUMP.

The different forms of Mr. Davey's engine, made by Hathorn, Davey, & Co., Leeds, have received the appellative 'Differential,' from the very ingenious and valuable self-governing arrangement of the valve-gear for proportioning the supply of steam to the varying pressures of the working load.

'The Differential engine exists in two distinct types, viz., the single-cylinder and the compound engine; the latter, admitting of being worked with very high-pressure steam and high degrees of expansion, is capable of realising the greatest economy of fuel. The chief peculiarity in the invention is the simple manner in which the engine is made perfectly safe in working under all conditions of load, automatically and instantly varying its supply of steam with very minute increase or decrease of resistance, the distribution of steam being such that the pumping is performed without shock, even when the pressures suddenly and greatly vary.

There are two forms of Single-cylinder engines: the *Differential Steam-pump*, and the *Single-cylinder Differential pumping engine*, both for use underground. Of Compound-cylinder engines there are three forms, *Vertical and Horizontal engines*, used at the surface for actuating pump-rods, and the *Horizontal engine*, applied underground, see fig. 136. The Single-cylinder Differential engine and the Differential Steam-pump have already been noticed. Before considering the underground Compound Horizontal engine let us explain the nature of that feature in these engines which distinguishes them from other engines—the Differential Valve-Gear.

'The main principle of the gear is that the valves of the engine have a motion the resultant of two other motions, the first an independent constant motion, and the other the motion of the engine, which may be termed a dependent variable motion. Any erratic movement of the engine resulting from a change of load, or other cause, produces a corresponding variation in the distribution of steam through the resultant motion of the valves.'

The principle of the gear is represented by the illustration on page 218 (fig. 137), which is a perspective view of the gear as applied to engines having drop-valves and to existing Cornish engines. 'It consists

of a lever called the main lever, by means of which motion is given to the valves through a rod. The motion of the engine is given to the outer end of the lever through the rod by means of a lever of the first order, the long end of which is attached to the plug-rod, the other end deriving its motion from the subsidiary cylinder, and being controlled by means of the cataract. The cylinder has a slide-valve, which is worked by means of a tappet arm on the rod of the piston of a secondary cylinder; the motion of the secondary piston is also controlled by a secondary cataract. The slide-valve is, however, free to move with the motion of the hand-lever. It will be seen that there are two hand-wheels and a hand-lever attached to the cataracts. The function of the large wheel is to regulate the speed of the engine during the stroke; the small wheel is for regulating the pause between the strokes, whilst the hand-lever enables the engineman to hand-work the engines. The rocking shaft is employed to give motion to the valves of the engine in the usual way, clearly shown in the engraving.

'The action of the gear may be thus described: Let the engines be "out-doors." The engine end of the main lever will then be in its highest, and the opposite end in its lowest position, the secondary lever being lifted so as to admit steam to the bottom of the secondary cylinder. The engine will pause until the piston of the secondary cylinder shall have travelled to the end of its stroke, and have lifted the valve of the subsidiary cylinder. The pause will be long or short, according to the regulation of the secondary cataract. The piston of the subsidiary cylinder then having steam on its lower surface will travel upwards, actuating the main lever with a speed dependent on the adjustment of the cataract. In doing so the steam-

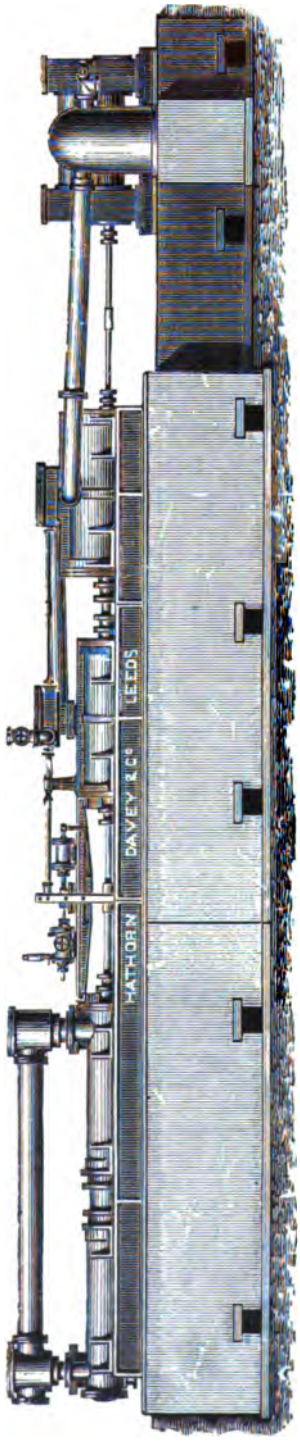


FIG. 136.—Davey's Differential' Compound Plunger-Pump.

valve of the engine will be opened through the medium of the rod, and the rocking-shaft, etc., and will be opened quickly, because the engine end of the lever is, for the time being, stationary. Steam now being admitted on the engine-piston, it will, after overcoming the inertia of the load, move

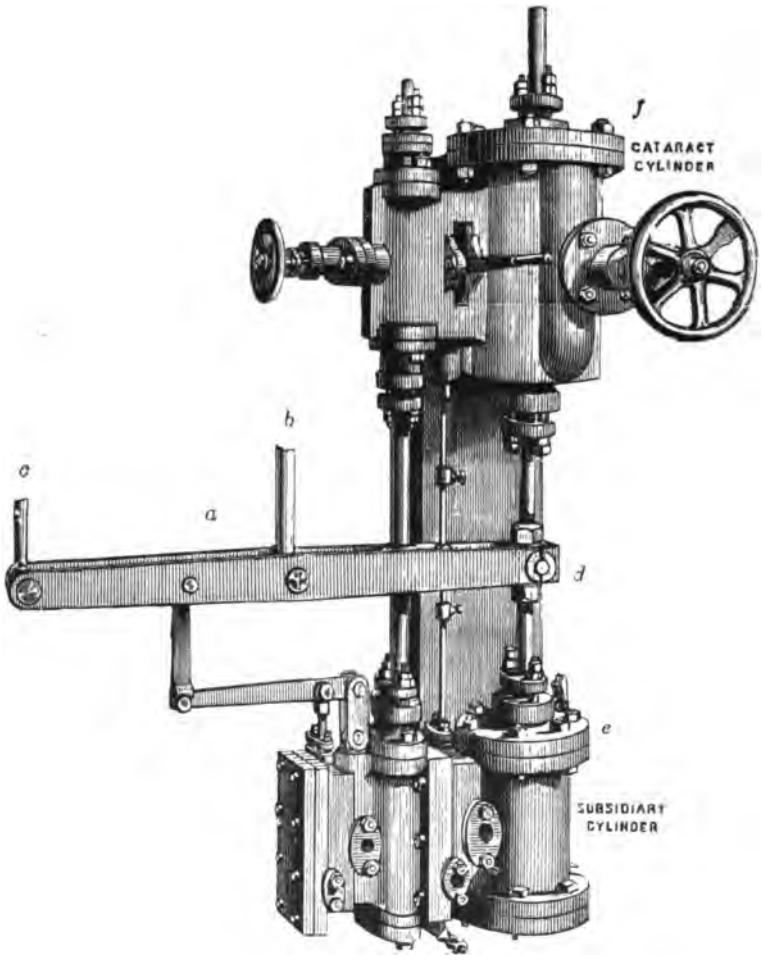


FIG. 137.—Differential Valve Gear as applied to Cornish Engines.

off at an increasing speed, which is communicated to the engine end of the main lever. The result is, that as the opposite end of the lever is moving uniformly in the opposite direction at the same time, the motion of the centre is soon reversed in direction, and the steam-valve, which was opened by the motion of the subsidiary piston, is closed by the differential

motion brought into action by the motion of the main piston acting on the same point.

'It will be seen that the valve of the differential will only be changed by a change in the motion of the engine, because the other component of the differential is a constant, and the time of closing the steam-valve will be earlier or later as the differential is greater or less; and as changes in the motion of the engine are produced by variations of load and steam-pressure, it therefore follows that these variations produce their correction in the distribution of steam.

'If through loss of load the motion of the piston of the engine becomes excessively erratic, steam will, by the action of the gear, be admitted on the reverse side. The full load has often been suddenly thrown off from a differential engine moving at its normal speed without any damage resulting.'[1]

The Differential valve gear is further illustrated by the accompanying figures (138 to 141), which represent the gear as applied to the compound engine. 'The diagrams are not drawn to scale, but are intended to show clearly the action of the gear. The main slide-valve, G, is actuated by the piston-rod, through a lever, H, working on a fixed centre, which reduces the motion to the required extent and reverses its direction. The valve-spindle is not coupled direct to this lever, but to an intermediate lever, L, which is jointed to the first lever, H, at one end; the other end, M, is jointed to the piston-rod of a small subsidiary steam-cylinder, J, which has a motion independent of the engine-cylinder; its slide-valve, I, being actuated by a third lever, N, coupled at one end to the intermediate lever, L, and moving on a fixed centre, P, at the other end. The motion of the piston in the subsidiary cylinder, J, is controlled by a cataract-cylinder, K, on the same piston-rod, by which the motion of this piston is made uniform throughout the stroke; and the regulating plug, Q, can be adjusted to give any desired time for the stroke.

'The intermediate lever, L, has not any fixed centre of motion, its outer end, M, being jointed to the piston-rod of the subsidiary cylinder, J; and the main-valve, G, consequently receives a differential motion compounded of the separate motions given to the two ends of the lever L. If this lever had a fixed centre of motion at the outer end, M, the steam would be cut off in the engine-cylinder at a constant point in each stroke, on the closing of the slide-valve by the motion derived from the engine piston-rod; but, inasmuch as the centre of motion at the outer end, M, of the lever shifts in the opposite direction with the movement of the subsidiary piston, J, the position of the cut-off point is shifted, and depends upon the position of the subsidiary piston at the moment when the slide-valve-closes. At the beginning of the engine-stroke the subsidiary piston is moving in the same direction as the engine-piston, as shown by the arrows in fig. 138; and in the instance of a light load, as illustrated in

[1] *Engineering.*

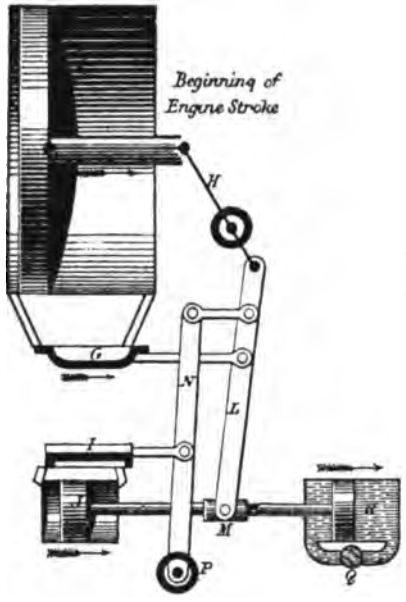


FIG. 138.

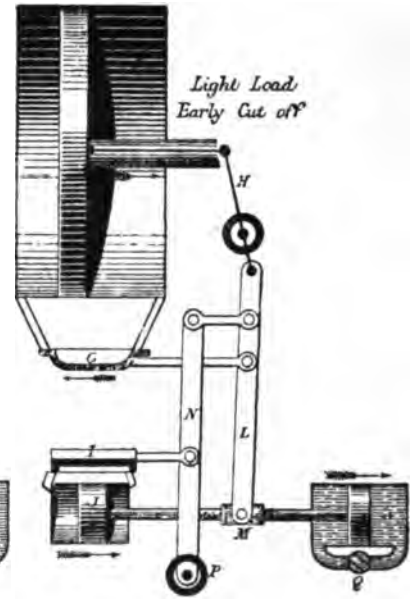


FIG. 139.

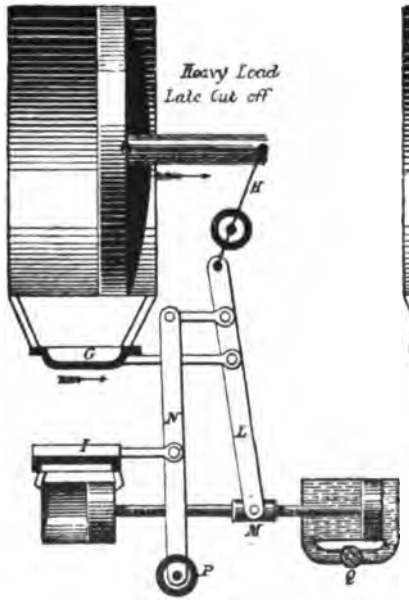


FIG. 140.

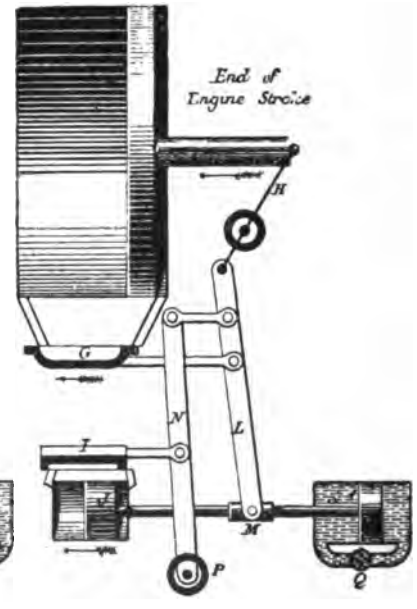


FIG. 141.

Diagrams illustrating action of Differential Valve Gear.

fig. 139, the engine-piston, having less resistance to encounter, moves off at a higher speed, and sooner overtakes the subsidiary piston, moving at a constant speed under the control of the cataract; the closing of the main valve, G, is consequently accelerated, causing an earlier cut-off. But with a heavier load, as in fig. 140, the engine-piston, encountering greater resistance, moves off more slowly, and the subsidiary piston has time consequently to advance further in its stroke before it is overtaken, thus retarding the closing of the main valve, G, and causing it to cut-off later. At the end of the engine-stroke, fig. 141, the relative positions become reversed from fig. 138 in readiness for the commencement of the return stroke.

'The subsidiary piston, J, being made to move at a uniform velocity by means of the cataract, K, the cut-off consequently takes place at the same point in each stroke, so long as the engine continues to work at a uniform speed; but if the speed of the engine becomes changed in consequence of a variation in the load—if, for instance, the load be reduced, causing the engine to make its stroke quicker—the subsidiary piston has not time to advance so far in its stroke before the cut-off takes place, and the cut-off is therefore effected sooner, as in fig. 139. On the contrary, if the load be increased, causing the engine-stroke to be slower, the additional time allows the subsidiary piston to advance further before the cut-off takes place, and the cut-off is consequently later, as in fig. 141. This adjustment of the cut-off point in accordance with each variation in the load is entirely self-acting, and takes place instantly, however sudden or extensive the variation in the load on the engine may be; consequently, the engine is rendered safe in working against variable loads, as it automatically and instantly varies the distribution of steam with every increase or decrease of the resistance.

'The force acting on the subsidiary piston, J, is much greater than that required for moving the slide-valve, the excess being absorbed in driving the fluid in the cataract-cylinder, K, through the small adjustable aperture, Q; and as the resistance of the fluid increases as the square of the velocity, a very small variation only in the speed of the subsidiary piston can be effected by a considerable variation in the force upon it; so that the speed is maintained practically constant for a given adjustment of the cataract-plug, Q, although the boiler-pressure of steam may vary. The main slide-valve, G, is opened at the beginning of each stroke by the motion of the subsidiary piston, which is controlled by the cataract; and a pause is consequently given at the completion of each single stroke of the engine, which allows time for the pump-valves to fall to their seats. Slip in the water is by this means prevented, as well as the shock which occurs when pump-valves close under the pressure from a moving plunger. This freedom from shocks in the pumps is an important point, giving safety from accidents, such as the bursting of pipes, and at the same time the durability of the valves and seats is materially increased.

'A plan of the differential valve-gear is represented in fig. 142: R is a connecting-rod which, with the long lever, H, fig. 138, communicates the motion of the engine-piston to the intermediate lever, L, of the valve-gear. An independent steam-starting or pausing-cylinder is shown at S, the piston-rod of which carries a rack-gearing into a pinion on one end of a tubular shaft, T; the other end of the shaft being made with a screw thread, its rotation traverses the outer end, P, of the lever N, of the valve-gear, and thereby opens the small slide-valve, I, of the subsidiary cylinder, J. The slide-valve of the pausing-cylinder, S, is moved by tappets by means of a lever which is actuated by the same lever, H, that works the inner end of the intermediate lever, L, of the valve-gear. The pausing-cylinder, S, is itself also controlled by a cataract-cylinder on the same piston-rod, and the length of pause after each stroke of the engine is consequently determined jointly by this and the cataract, K. The first regulates the time of opening the small slide-valve, I, for starting the subsidiary piston, J; after which this piston, under the control of the other cataract, K, has to travel a sufficient distance for opening the main slide-valve, G, of the engine. The adjustment of the cataract, K, also determines the mean piston-speed of the engine under the normal conditions of load and steam-pressure.'[1]

From the foregoing description of the valve-gear it will be understood that every erratic motion of the engine alters the relative position of the valves with respect to the main piston, and in that way the engine checks itself. So perfect is the action of this gear, that when properly adjusted the full load may be thrown suddenly off the engine without any injury resulting. The effect of a sudden loss of load is to reverse the action of the valves, and *to throw the steam against the motion of the piston, stopping it before the end of the stroke.* Many instances of this have occurred in practice when a pump-rod has been broken, a pump-valve has failed, or a pipe has been burst.

We will now proceed with a general description of Mr. Davey's engine.

Introduced in 1874, this engine has come very prominently to the front as one of the most efficient underground pumping engines in use. It has been applied to drainage operations of a very extensive character, and where the exigency of the case demands the employment of an underground engine we know of nothing better, although, in common with other types of underground engine, it cannot be said to offer a serious competition to a surface beam engine for economy. As a description of the engines of this type used in the Erin Colliery, Westphalia, will presently be given, and the 'Differential' valve gear, which is the most noticeable feature of the engine, having already been described, the following short description, with the illustration, fig. 136, will be sufficient.

The high and low-pressure cylinders are in a straight line with each

[1] Henry Davey, M.I.M.E., etc., *Direct-acting Pumping Engines and Pumps.* (*Proceedings Inst. Mech. Engineers*, Oct. 29, 1874, pp. 261-264.)

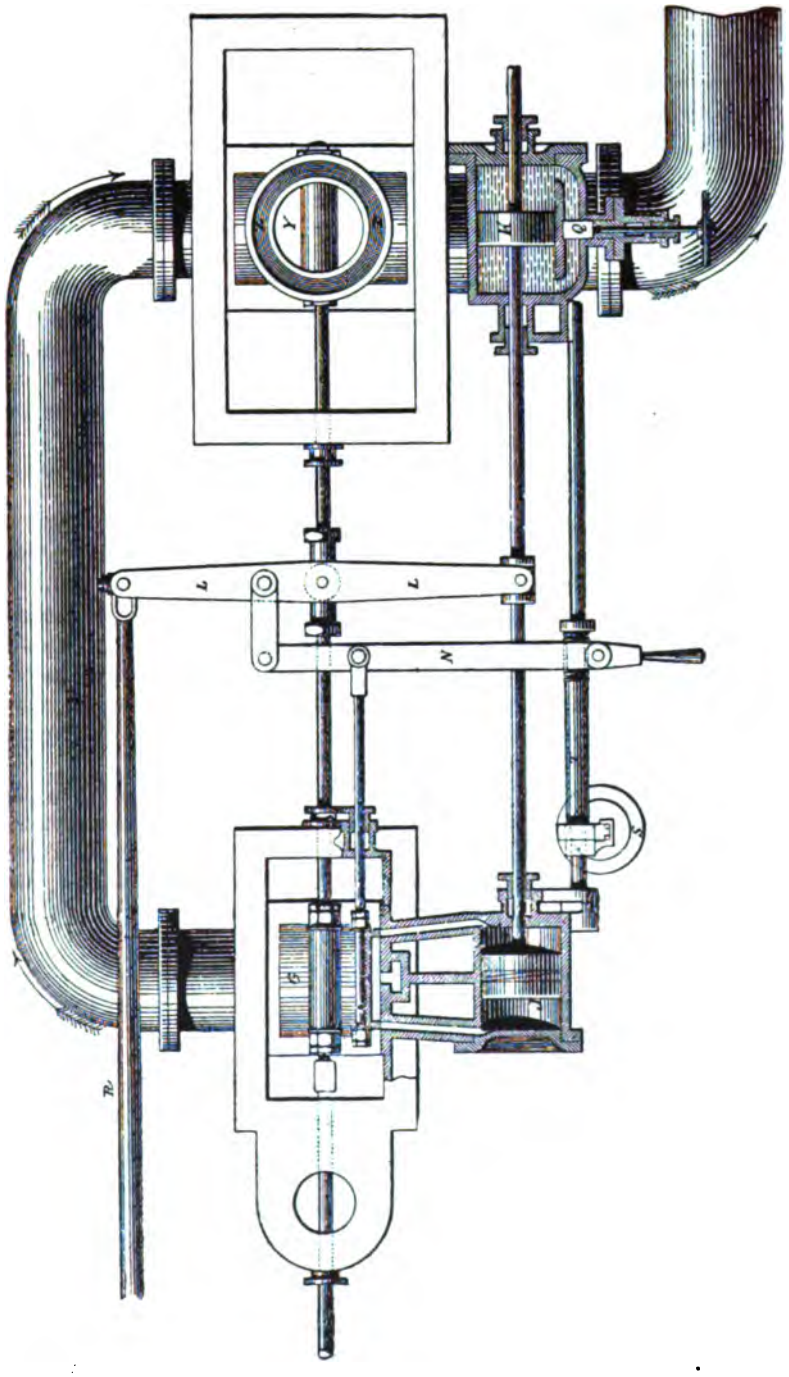


FIG. 142.—Plan of Differential Valve Gear. Scale $\frac{1}{24}$th.

other, and stand upon the same bed-plate. The two piston-rods of the low-pressure cylinder pass one on each side of the high-pressure cylinder, in tubes cast along the sides, and are united to the high-pressure piston in a strong wrought-iron crosshead, which also takes hold of the pump-rod. A rod from the low-pressure piston is carried through the cover of the cylinder, and works the air-pump of the condenser, which stands on a separate bed-plate. The pump consists of two working-barrels, or ram-cases, with a stuffing-box at each of the inner ends. A long hollow gun-metal plunger or ram reciprocates in the working-barrels. The pump-rod passes through the ram, and is secured thereto by a nut. The valves are of gun-metal, and are of the Harvey and West double-beat variety, with a low lift, and the valves and valve-seats are of such a size as to allow ample area for the passage of the water, by which the friction is reduced to a minimum. The valves lift against an india-rubber spring or buffer, which assists their closing rapidly and without any shock.

The suction valve-chests are attached one to each of the outer ends of the working-barrels, and the delivery valve-chests are fixed directly above them. Davey's Patent Separate Condenser is used in connection with this engine; by its application the makers claim that a very considerable increase of power is available, and a similar percentage saved in fuel. The air-pump, which is double-acting, is worked by a small 'differential' steam-engine. The air-pump valves are rubber disc-valves on gun-metal seats. By the use of this condenser the vacuum is maintained unimpaired when the engine is irregular in its working.

An adjunct to this engine is Davey's Patent Differential Hydraulic Pumping Engine, which precedes the main engine, and entirely removes the danger of its being flooded. The hydraulic engine is placed at the bottom of the pit, and it will work under water, and can be actuated from the main-engine room. The mode of its application is explained at pages 226–228.

The particulars given at page 183 of work done by Davey's compound engines will be interesting, as showing the magnitude of the drainage to which engines of this class have been applied.

With an engine of this type, and indeed all underground pumping engines, the mass of matter to be set in motion is very small, being only the weight of the column of water and the moving parts of the engine. The total weight of the mass does not exceed 1½ times the water-load; it usually is not more than about $\frac{1}{10}$ or $\frac{1}{8}$ greater. The ratio of expansion is consequently not high, and the high-pressure cylinder carries very nearly full steam. The expansion in the engines used in the Erin Colliery is about 3 to 1, which is all that is possible to get with the available inertia and momentum.[1]

Underground engines cannot be used for pumping out a pit in which

[1] Henry Davey, M.I.C.E., &c., *The Underground Pumping Machinery at the Erin Colliery, Westphalia.* (*Trans. Society Engineers*, June 12, 1876.)

the operation of sinking is being carried out without additional pumping apparatus. Mr. Davey places his engine at the surface and connects it to a pair of quadrants at the top of the pit, which are attached to pump-rods, and on the completion of the sinking operations the pumping-gear in the pit is thrown aside, and the engine is removed to or near the bottom of the pit. The engine can be retained at the surface to continue the drainage of the pit after it is sunk, should there be any objection to placing it underground. For pits already sunk to the required depth, this engine possesses some advantages over the Cornish engine. It permits the winding to be done in the same pit, owing to the inconsiderable space which the water and steam-pipes occupy. The water is raised in one direct lift, which is a much simpler arrangement than the Cornish lift; it does not require so much attention, and is far less costly, and the engine is very much cheaper than the Cornish engine. The working economy, however, is in favour of the Cornish system of drainage, and in metalliferous districts where coal is dear this is a very important consideration. Under such circumstances the underground engine can scarcely be said to offer a serious competition either to the Cornish engine or to Mr. Davey's surface compound engine. Many of the forms of pumping machinery we have already discussed have some particular sphere of operation in the mining field for which they have a special adaptation. This engine is peculiarly adapted for use in colliery pits already sunk, in which it is necessary to replace worn-out machinery, and to enable winding to be done in the same pit, or to supersede the pump-lifts used during the course of sinking, when the whole of the pit is wanted for winding.

This engine appears to give satisfactory evidence of durability. The engines used at the Erin Colliery (up to June 1876 [1]) had been working for nearly two years, night and day, without stopping, except for the grinding-in of the pump-valves when they got indented by grit or from any other cause. That occurred, perhaps, once in two or three months. The pistons had not perceptibly worn.[2] Impure water, or water containing grit, affects the rams and valves more than any other parts. Cast-iron valves become useless in a few days, and brass valves after a few weeks generally require refacing. These difficulties have led to the adoption in some instances of valves compounded of hippopotamus hide and brass, which give much better results.

The following is an account, extracted from the 'Trans. Soc. Engineers,' June 1876, of Davey's Differential Compound Engines, used at the Erin Colliery, Westphalia; it is perhaps the largest example of underground pumping machinery extant:

[1] This colliery was inundated in the following year, and some years afterwards was acquired by a German company (see p. 228).—S. M.

[2] *Trans. Soc. Engineers*, June 1876: Davey's Account of the Underground Pumping Machinery at the Erin Colliery.

'The pit is 1,200 feet deep, and the pair of steam-engines and hydraulic engines combined are together capable of delivering the required quantity of 1,000 gallons of water per minute, or 60,000 gallons per hour, to the surface. At a point 900 feet below the surface are placed a pair of compound differential pumping engines, as shown in the section . . . with separate condensers. Each engine is capable of raising 500 gallons per minute to the surface, and at the same time of supplying power to a pair of hydraulic pumping engines placed at the bottom of the pit, and employed in raising 500 gallons each per minute to the main engine. Each engine has a massive girder bed of cast-iron, with a 35-inch high-pressure and a 60-inch low-pressure cylinder, 6-feet stroke. The normal speed of the engine is 12 strokes per minute. The slide-valves for these cylinders are actuated by the author's patent differential valve-gear. The pistons are fitted with metallic packing. The pumps are double-acting ram-pumps, 12½ inches diameter, 6 feet stroke, with rams of gun-metal. The pump-rods, 5¾ inches diameter, pass from end to end of the rams, and are secured thereto by gun-metal nuts. The piston-rods and pump-rods are united in one strong wrought-iron crosshead, supported and guided in cast-iron slide-bars. The pump-valves are of gun-metal, double-beat, 11 inches in diameter, and low lift, allowing ample area in the water-passages, and thus reducing friction to a minimum. The suction-pipes are 10 inches diameter, and the rising-main 14 inches diameter; all the joints of the pumps and pipes are of the well-known hydraulic type, made with gutta-percha.

'Each pump is provided with a sluice-valve on the delivery side, 10 inches in diameter. There is one condenser to each engine. The steam-cylinder is 14 inches diameter and 3 feet stroke, working a double-acting air-pump 16 inches diameter and 3 feet stroke. The air-pump valves are rubber disc-valves on gun-metal seats. Each condenser is of sufficient capacity for both engines, and the connections are so arranged that either or both engines can work from either or the same condenser, thus allowing one condenser to be under repair if necessary. By the application of the separate condenser the vacuum is maintained unimpaired when the engine is irregular in its working.

'At the bottom of the pit, 300 feet below the main-engines, are placed a pair of hydraulic engines which lift 1,000 gallons per minute to the main engine,[1] at a speed of 12 strokes per minute, whilst the main engines

[1] 'But it is necessary for the main engines to lift more than that quantity, because there are 1,000 gallons of water as a feeder at the bottom of the mine, and it is required to deliver that quantity on the surface. If 1,000 gallons only be lifted by the main engines, the quantity delivered to the surface would be only the difference between the quantity lifted by the hydraulic-engines and that required to work them. There is a certain quantity of water made available in the rising-main for working the hydraulic engines, and in order to provide that quantity it is necessary to make the pumps on the main engines so much larger. The main engines really pump to the surface 1,400 gallons per minute, or what is equivalent to it. They pump it against the head due to

finally force the water to the surface, and at the same time, through the column, supply power to work the hydraulic engines.[1] The hydraulic engines consist of double-acting power rams, and pumps placed face to face on the telescopic principle. These engines are self-contained on a strong girder bed similar to that of the steam-engine. The pumps which are placed at each end of the bed are 14 inches in diameter, and of the ordinary ram type, with gun-metal double-beat valves, and brass-covered rams 12 inches diameter and 5 feet stroke. The two rams are connected to each other by two strong wrought-iron side-rods, and thus alternately pull one another in their return stroke. The power rams, which are 7 inches diameter, are wholly of gun-metal, and of the same stroke as the pumps. They are connected at one end to a central valve-box, and being cast hollow admit the pressure to the cylindrical rams of the pumps. All the bearings and glands are brass-bushed. All the packings are easy of access, and are applied only in stuffing-boxes.

'The main-valve box is placed in the centre of the engine, and contains four valves, $5\frac{3}{4}$ inches diameter, two being supply and two exhaust, which communicate with their respective pumps. The valves are cylindrical, gun-metal, mitre valves, $6\frac{1}{2}$ inches diameter at the top, and provided at their cylindrical ends with double cup-leathers. They are of large diameter and low lift, thus reducing friction and wear and tear to a minimum. The method of actuating these valves has been patented by the author, and consists in lifting and closing the valves by water-pressure. The upper or cylindrical portion of the valve is of rather larger diameter than the valve proper, consequently the pressure from the main lifts this valve, and admits pressure to the power-ram. On the return stroke this valve is closed by admitting pressure on the large area at the top of the valve, whilst a corresponding but intermittent action takes place with the relief-valve. The main valves thus rise and fall by the alternate admission and cutting off the water-pressure, which is further regulated by a modification of the differential gear applied to the two small change-valves. One end of the intermediate lever is actuated by the hydraulic cylinder, which is $2\frac{1}{2}$ inches diameter and 8 inches stroke, and has an independent motion, regulated by a small slide-valve in the change-box, whilst the other end of the lever is worked by suitable rods and levers from the engine itself. The small valve contained in the change-box admits or relieves the pressure upon the main valves. The slide-valve for the cataract-cylinder has no lap, but the slide-valve for the main-valve box has a negative lap; the length of time therefore governed by the cataract occupied by the small slide-valve in

the distance from the engines to the surface. 1,000 gallons are pumped to the surface, and the other 400 gallons pass down and act simply as a medium—a water spear in fact.'

[1] 'The available head for driving the hydraulic engines is the head of water above the main engines; this is the effective head. The head between the main engines and the hydraulic engines being the same, the two columns of course balance each other, and as far as the supply is concerned the water that goes down is simply that which gives power to the hydraulic engines.'

traversing the negative lap, gives a pause to the engine at each end of the stroke, as both supply and exhaust-valves are closed until the small slide-valve travels a certain space. This pause allows time for the pump-valves to fall to their seats. Slip in the water is by this means prevented, as well as the shock which occurs when valves close before a moving plunger.

'The main and hydraulic engines are quite independent in their motion. That is to say, that the strokes are not identical or synchronal. The hydraulic engines work from a reservoir of power, that reservoir being the rising-main from the main engines, and as long as there is water in the main, the hydraulic engines may be worked at any speed within the maximum. By this hydraulic system of underground pumping the main engines are kept out of danger of flooding. The hydraulic engines will work under water, and can be actuated from the main-engine room. As a further security they could be placed in a water-tight staple, and by such means the hydraulic engines could be under repair even when the water rose to the main engines 300 feet up the shaft.'

Mr. Mulvany, writing to Messrs. Hathorn, Davey, & Co. from Hans Goldschmieding, Castrop, under date Sept. 5, 1898, says:

'The underground pumping engines at Erin Colliery, Castrop, built and erected by your company, gave complete satisfaction, but the mine was drowned out in 1877 by an immense influx of water, and the colliery passed into German hands; some years later on the pit was pumped out by powerful plant erected overground, and the managers of the German company informed me that the engines had suffered so much from the effects of lying so long under water that they had to be broken up, and sold for scrap iron.'

At the Nixon's Navigation Colliery, South Wales, the author inspected one of Mr. Davey's engines at work underground about 1,100 feet from the surface. It had a high-pressure cylinder of 28 inches, and a low-pressure cylinder of 50 inches, with a 4½-feet stroke, working a double-acting ram of 12 inches diameter. The suction and delivery-pipes were 10 inches diameter. The steam was taken down the pit in a 12-inch pipe and along a heading, to a receiver at the back of the chamber, in which was the Davey engine; a branch pipe of 6 inches supplied the engine, the remainder of the steam being used for working two pairs of hauling-engines (26 inches and 24 inches) and a blocking-engine (12 inches). It was used at a pressure of from 40 to 43 lbs., and the engine kept the water at 4½ strokes per minute. The water was taken from a lodge-room about 220 yards from the surface. At the time of his visit there was an hydraulic engine of 4½-inch cylinder, ready fixed on the same floor as the large engine, and designed to take the water from a lower point, but it had not yet been used. The suction and delivery were 4 inches; the ram was double-acting, in a chamber 6 inches in diameter. The water would be discharged into the suction-pipe of the large engine. The actual horse-power of the plant was 160, equal to raising 500 gallons per minute 1,100 feet high at 10 strokes per minute. Weight of the engine and pumps 46 tons.

At a meeting of the National Association of Colliery Managers at Manchester, February 28, 1893, the President (Mr. W. W. Millington) read a paper descriptive of the pumping plant then recently erected at Woodpark Pit, Barnsley, belonging to the Chamber Colliery Company, Ltd., and also the result of a trial made on February 11, 1893, by himself and the company's engineer and staff. The following abstract of this valuable paper will be read with interest. The engine was installed at the bottom of the pit, and is of the direct-acting compound condensing underground colliery type made by Hathorn, Davey, & Co., of Leeds, and fitted with Davey's patent differential gear. The cylinders are unjacketed, 15-inch and 26-inch diameter, and the pumps are of the differential ram type, 5-inch and 7¼-inch diameter, all by 3-feet stroke. The air-pump is double-acting, 8-inch diameter, worked from the low-pressure cylinder tail-rod. The engine is fixed near the bottom of the winding, or downcast shaft, its nominal duty being to raise 100 gallons of water per minute a vertical height of 1,341 feet. Having a differential ram, it has only one suction and one delivery valve, although double-acting, this being of great value under such a heavy pressure. The valves and seatings are made of cast steel, and are of the equilibrium type, but on the faces of the valves there is a lip turned, and corresponding to it a recess in the seatings which is filled with woodite, thus procuring a silent action and a perfectly tight face, which is a great consideration under a head of 1,341 feet. The engine is fitted with 6-inch exhaust pipes, which go from the low-pressure cylinder to the upcast shaft, and on starting the pump the steam is turned through them, until the air-pump has got hold of its water through the condenser, and thereby actuating one valve. The passage to this exhaust is closed, and at the same time the passage to the condenser is opened; by this means all chance of steam escaping into the engine-house is avoided. The engine-house is provided with three fire hydrants, on which there is a pressure of water of 70 lbs. to the square inch. This water is collected at an old mouthing up the shaft, and brought to the engine-house through 1-inch wrought-iron steam-pipes. It is connected to the condenser to assist the air-pump when required, and also connected to the suction-pipes of the pump so that the attendant, by opening a valve, can fill the suction-pipes, pump chambers, etc., solid before starting the pump. There is a vacuum vessel also fixed on the suction pipes. The engine is supplied with steam at 80 lbs. pressure (the safety-valves being loaded to 100 lbs.) by two steel Cornish boilers fixed underground near the upcast shaft, and about fifty yards from the engine. The boilers are 18 feet long by 5 feet 6 inches diameter, the flues being 2 feet 9 inches diameter, and were made by Messrs. Tetlow Bros., Hollinwood, on their most modern principle, all plates being planed on the edges, rivet holes drilled in place, flue and mud holes, etc., bored out, and all hydraulic-riveted. These boilers supply steam to the hauling-engines; but on the occasion of the trial the pit was stopped. The boiler house is 45 feet by 26 feet inside the main walls, and 11 feet

high in the clear. Between the boilers there is a wall 3 feet thick, which is run up to the roof, for the support of wrought-iron girders 12 inches deep, and these are covered with boiler plates, thus making a substantial roof with the maximum of room. There is a 3-feet passage all round the boilers, so that all danger of crushing is avoided, and they are fed with fresh air from the downcast shaft. As the water made in the shaft is not fit for boiler use, the feed water required is brought from the surface to a point 100 yards from the bottom of the shaft, where there is fixed a small tank, from which the water is piped to the boilers and fed direct, the pressure due to 300 feet head, dispensing with donkey pumps or injectors. The rising main is 5 inches internal diameter at the bottom of the shaft, increasing to 6¼ inches diameter at the top, the outside diameter of 8 inches being maintained all through. There are three non-return valves placed at regular intervals in the length of the column. The trial lasted 3 hours 30 minutes, and indicator diagrams were taken every half-hour; the number and length of strokes were taken every quarter of an hour, also the number of gallons delivered, as indicated by a notch board set in the delivery culvert on the surface. The average working stroke was 2 feet 11½ inches, the maximum variation being 3 per cent. The average number of double strokes was 23½ per minute, the minimum being 22 and the maximum 24. The total quantity of water that should have been pumped during the trial, calculated from actual ram-displacement, was 26,040 gallons. The water passing over the notch board amounted to 25,200 gallons, 120 gallons per minute, showing a slip of 3·6 per cent. The average indicated horse-power amounted to 59, and the pump horse-power to 50, giving a mechanical efficiency of 85 per cent., including the friction through the rising main. No diagrams were taken from the pump, as the pressure was too great for the indicator, but a pressure gauge was fixed upon the delivery branch, the pointer of which vibrated from 250 to 700 lbs. The trial commenced with steam up; at 80 lbs. the fires were examined, and the level of the water in the gauge glasses was noted, all the conditions being maintained at the end of the trial. The feed water entered the boiler at a temperature of 48 degrees Fahr.; 750 gallons were used during the trial (as ascertained by meter), being equal to 43 lbs. per pump horse-power per hour, or 36·4 lbs. per indicated horse-power per hour. The coal used was that known as 'tops,' the quantity burnt being 9 cwts., or 5·76 lbs. per pump horse-power per hour, or 4·88 lbs per indicated horse-power per hour, equal to 1 lb. of coal evaporating 7·44 lbs. of water. The temperature of the hot well at the beginning was 101 degrees Fahr., and gradually rose to 125 degrees Fahr. The vacuum commenced at 24 inches, and during the first half-hour rose to 25½ inches, and this was maintained for two hours, when it gradually decreased to 23½ inches at the conclusion of the trial. The temperature of the water in the pump was 67 degrees Fahr. at the commencement, and 98 degrees Fahr. at the conclusion of the trial. The cylinder drains and the exhaust from the subsidiary cylinder were led into the condenser. The

amount of water in the steam was not ascertained; but this was probably fairly low, as the cylinders and steam pipes were carefully covered with non-conducting material. The trial fairly represents the ordinary working of the pumping engine from day to day. The cost of pumping during the three and a half hours was as follows :—

	s.	*d.*
9 cwt. of 'tops' at 5*s.* per ton	2	3
Wages	3	2
Oil, tallow, packing, waste, etc.		7
	6	0

= to 2·85*d.* per 1,000 gallons raised 1,341 feet high.

The colliery owners report: 'The pump works most satisfactorily, and has given us no trouble since the makers handed it over. Before they did so the cottered end of the ram broke through a flaw in the cast-iron, with the full load, and here the differential gear proved its value, as the full stroke was made and reversed without any further damage. The makers at once put in a steel ram, which has worked well since. The boiler duty may appear low, but it must be considered that they (the boilers) are very short, and the gases are discharged into the upcast shaft, or chimney, at a great heat, from which we get an advantage, as it produces us 47,000 cubic feet of air per minute after it has left the boilers. The total horse-power developed per week in the pumping engine, the hauling engines, and the ventilation is 408,000 on a total consumption of 13 tons of "tops," whereas, before the boilers were put down, we used from seven to eight tons per week for ventilation only, and an air-compressor on the surface supplied the hauling engines with motive power, and in addition it took seven hours each night to wind water.'[1]

The 'Tipton' Compound Plunger-Pump.

The 'Tipton' Compound Steam-Pump (Howl and Attwood's Patent) is an arrangement which for compounding combines the high and low-pressure areas within one cylinder. The external appearance differs materially from the usual design of direct-acting steam-pumps, and this is probably the only compound of the kind hitherto designed with the steam-chest underneath the cylinder. There are several important reasons for placing the steam-chest in this position, and the design of the steam-cylinder and valve gear lends itself admirably to the purpose. The self-draining facilities obtained by placing the steam-chest and ports under the cylinder are most important, as by so doing all condensation must drain to the exhaust by gravity, and the piston is thus enabled to automatically sweep the slightest accumulation of water away at every stroke. The steam economy is thus greatly increased by keeping the cylinder dry; but when, by reason of bad design, this is not possible, it becomes a serious matter, not only as regards steam economy, but also from the risk of breaking the cylinder-covers, etc.,

[1] From *The Colliery Manager, and Journal of Mining Engineering*, April 21, 1893, pp. 62, 63. (By permission.)

when such a pump is fixed several hundred yards from the boilers in a mine or similar position either for steam or air as a motive power. The steam-chest when located under the cylinder is out of harm's way and takes up less space than in any other position; also this situation being the lowest point, a steam-trap attached to the starting-lever pocket will receive the condensation from the steam inlet pipes and prevent water entering the cylinder. Reference to the accompanying illustrations and notes will explain the internal mechanism of this pump.

Fig. 143 is a perspective view of the 'Tipton' Compound Pump, which clearly defines the compound steam-cylinder with the steam-chest in

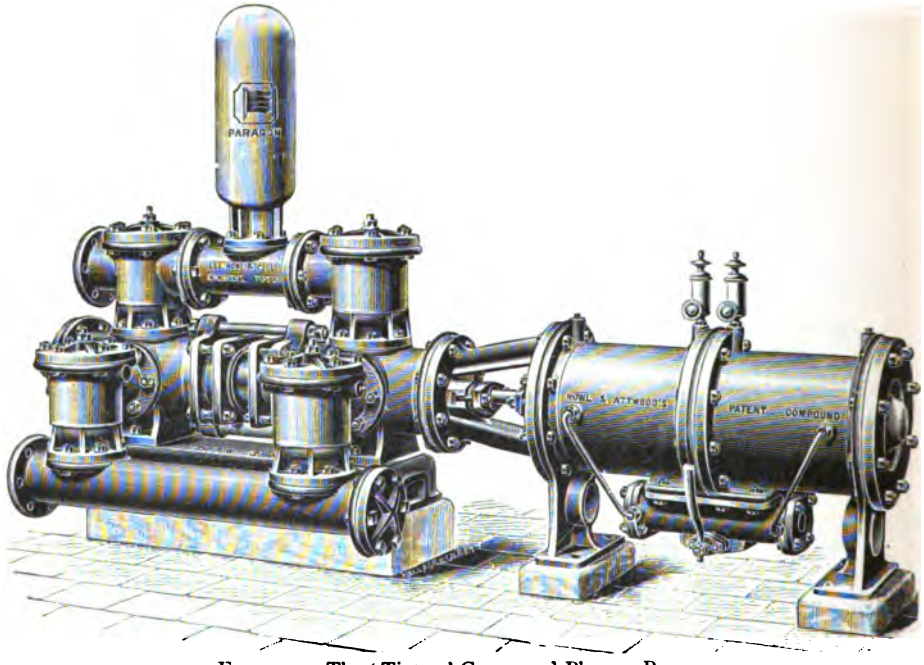


FIG. 143.—The 'Tipton' Compound Plunger-Pump.

position, and shows the water end to be of the 'Outside Centre-packed' Ram type. Fig. 144 is a sectional elevation through the centre of the cylinder and steam-chest; figs. 145 and 146 are cross sections through the lines A B and C D respectively. It will be observed, by referring to fig. 144, that the cylinder is divided in the centre of its length by the division ring, G; F is a trunk connecting the two pistons, E and E′, which latter are held in position by the shoulder and nut on the piston-rod, as shown. The junk ring, R, is secured by screws to the division ring, G, which holds an adjustable cast-iron ring to clip the trunk, F, and so forms a joint between the two high-pressure areas which are formed by the annular

spaces between the trunk, F, and the cylinder walls. The low-pressure areas are the full diameter of the cylinder at the outer ends of the pistons, E and E′. The cylinder feet are shown at X and X′. The steam-chest contains one piston-valve, P, the latter being operated by live steam

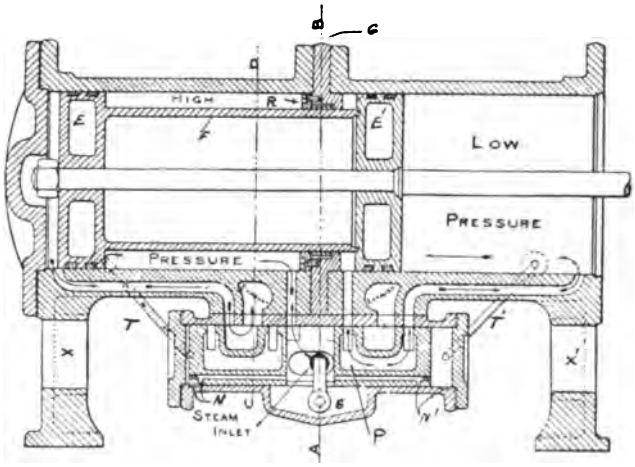
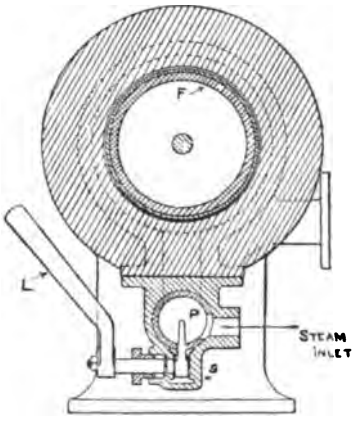
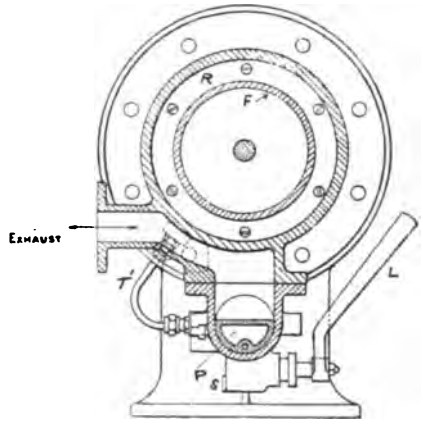


FIG. 144.



SECTION ON LINE A.B.

FIG. 145.



SECTION ON LINE C.D.

FIG. 146.

The 'Tipton' Compound Plunger-Pump; sectional elevation and cross-sections of the steam-cylinder, &c.

conveyed alternately from the high-pressure areas in the cylinder by pipes or passages, T and T′. The cylinder and valve-chest have three pairs of steam-ports, each pair in turn performing the functions alternately of distributing the live steam to the high-pressure areas, thence to the low-

pressure areas and again to the exhaust. Live steam is conveyed to the centre of the piston-valve, P, and then flows in the direction depicted by the arrows. L is the starting lever, and S indicates the lowest position in the steam-chest where condensation from the steam-pipes may be caught and drained away by the aid of a steam-trap before being allowed to enter the steam-cylinder. According to the illustration the stroke of the pump is nearly completed from right to left, the steam from the left high-pressure area is flowing through the pipe or passage, T, to reverse the piston-valve, P, after which the direction of the steam, indicated by the arrows, will be reversed, and so cause the pump to make another stroke from left to right until the pipe or passage, T′, is uncovered to the high-pressure area by the piston, E′, when another reversal takes place in like manner, and so on. There are only two live steam passages, Y and Y′, in the piston-valve, P, which alternately communicate with the pipes or passages, T and T′. The exhaust-passages for the piston-valve, P, are formed in the steam-chest casting, and communicate with the annular grooves cut in the piston-valve, P, opposite to the exhaust port or passage, M and M′. Should the piston-valve, P, overrun its proper length of stroke, it is cushioned by live steam which is admitted by passages, N and N′, from the centre of the steam-chest. The piston-valve, P, may be withdrawn from the steam-chest by removing one of the end covers, lowering the starting-lever into the recess, S, and then sliding it through one of the holes of the cylinder feet, which is provided for the purpose. This is a convenience when the pump is going to stand for a considerable length of time, as it allows all water to drain out of the cylinder, thereby preventing unnecessary corrosion and possible trouble when re-starting. Another point in favour of the trunk compound cylinder is the facility and low cost by which its power may be increased or diminished, or the expansion of the steam may be varied if desired by simply varying the diameter of the trunk and division ring, G, whilst the same cylinder and valve gear may be retained. The heat being contained in one cylinder, less radiation takes place than is the case when compounding with two separate cylinders. There is another advantage which merits attention, viz. :—that the packing-gland of the piston-rod is subject to low-pressure steam only, consequently less friction is required to keep it tight, and therefore the rod will have a much longer life than one where the packing has to resist high-pressure steam.

Under this arrangement a much lower initial steam-pressure may be compounded with advantage than is usually the case when the two separate cylinders are employed for the purpose. The reason for this is due to the fact that the radiating surfaces are much reduced, consequently there is less condensation, and the steam is enabled to perform all its functions before leaving the cylinder, and all outside exhaust pipes or passages are avoided until the exhaust steam is admitted to the atmosphere or condenser.

This pump certainly appears to possess many advantages which will

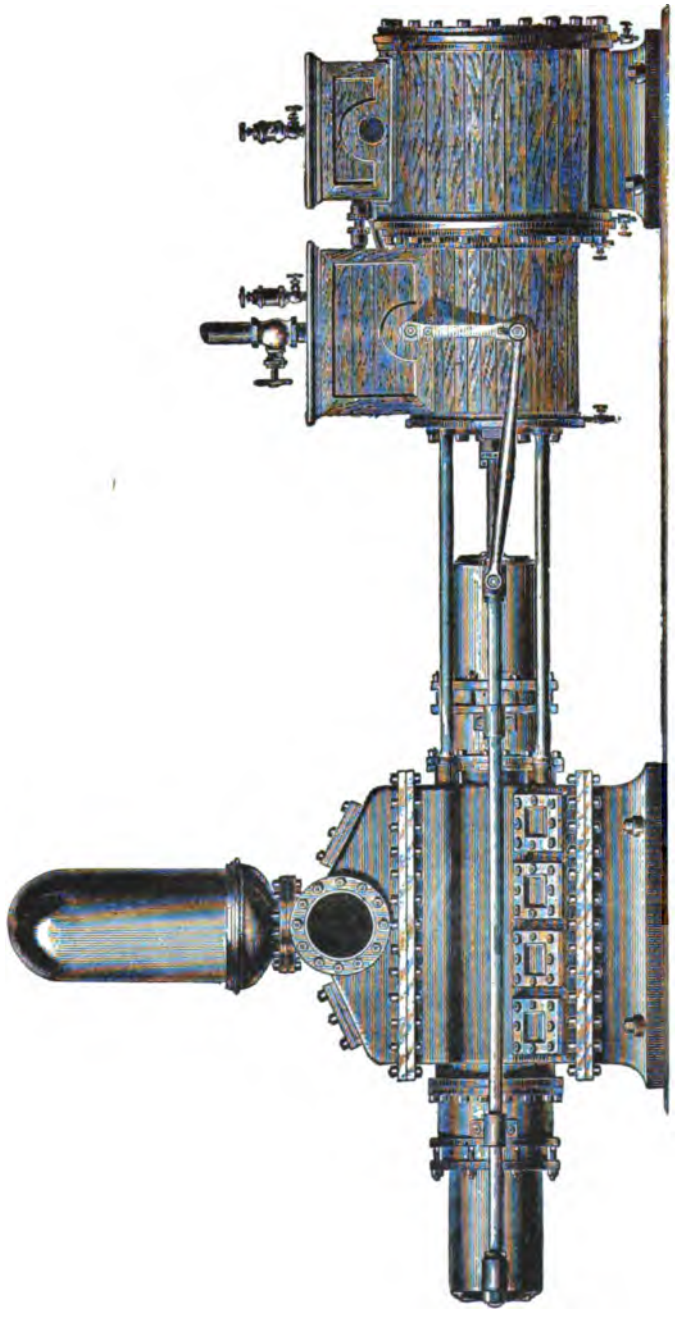


FIG. 147.—The 'Davidson' Compound Plunger-Pump.

recommend it for mining purposes: we understand the pumps already supplied are giving great satisfaction. Makers, Messrs. Lee, Howl, & Co., Ltd., Tipton.

The 'Davidson' Compound Plunger-Pump.

Fig. 147 is an adaptation of this engine to a plunger arrangement of water end. It will be observed there are two single-acting plungers working into each end of a pump-cylinder, having a central partition and delivering from their inside ends. The arrangement shows a centre connection for the front plunger and a side connection, by means of a crosshead and side-rods, for the rear plunger. The makers are Messrs. W. H. Bailey & Co., Ltd., Manchester

3. TWIN COMPOUND STEAM-CYLINDER, EXPANSIVE, CONDENSING ENGINES, WORKING DOUBLE-ACTING PISTON-PUMPS.

Compound Duplex Pumps.

For situations where economy of steam is a prime essential, and where the circumstances of accommodation, immunity from injury, and security

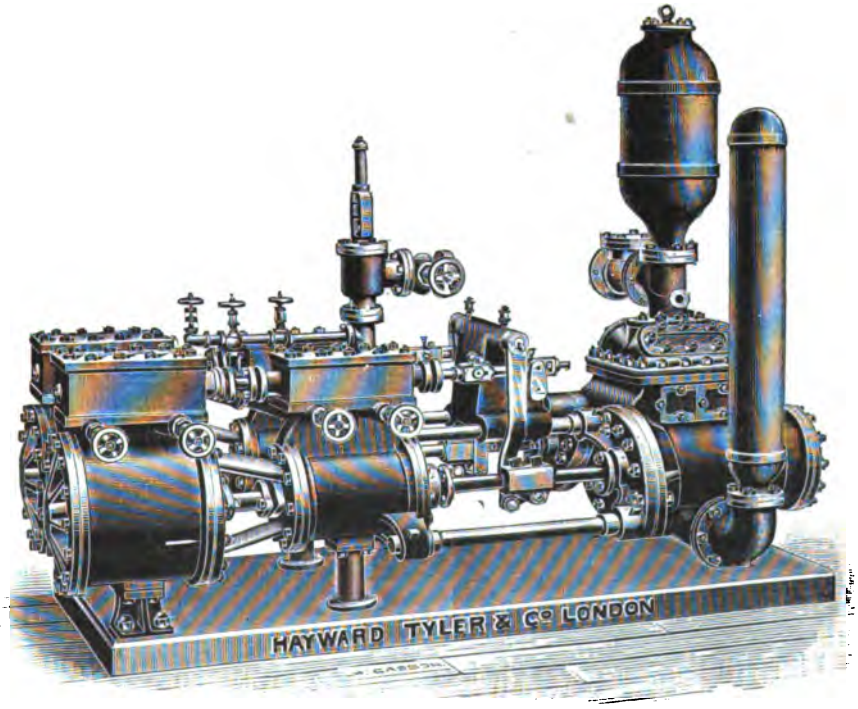


Fig. 148.—Hayward-Tyler & Co.'s Compound Duplex Piston-Pump.

from 'drowning-out' will admit of the use, these pumps may be adopted with some advantage. If, however, the water is bad, the plunger form of the pump should be employed.

To be used with safety they must be located in a 'station' remote from the sump, a sinking pump delivering to it, and to prevent injury to the valve gears and other delicate moving parts from falling fragments of rock and earthy matter, the excavation, unless in firm, hard rock, should be walled with masonry.

These engines stand in the same relation to the simple form of duplex engines as the ordinary compound engine to its more elementary congener.

Consuming from about 25 to 35 per cent. less fuel than the simpler form of duplex pumps, the greater first cost of these pumps may be justified for

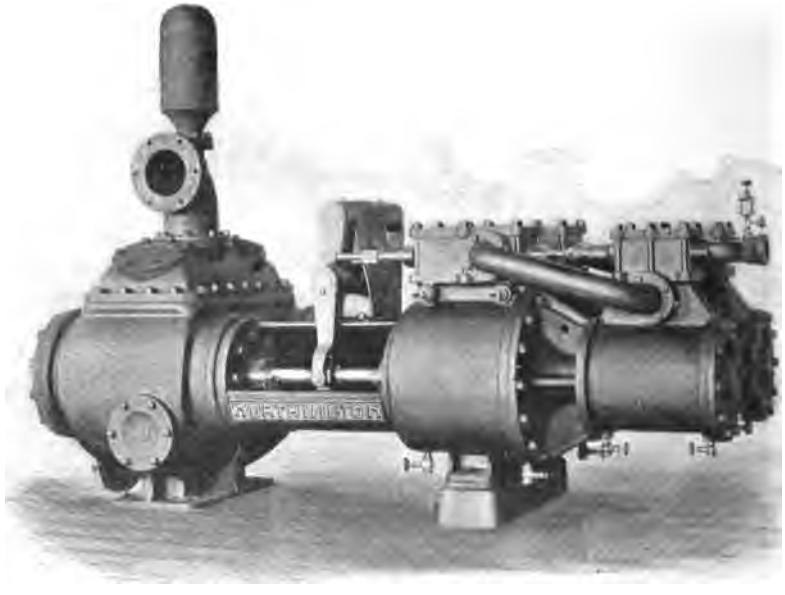


FIG. 149.—The Worthington Compound Piston-Pump (Compound Duplex).

situations where the use of a surface engine is impracticable. They do not appear, however, to be largely used for underground mining purposes in this country. Having previously given adequate descriptions of the simple class, it will be unnecessary to offer any explanation of the construction of these pumps, the illustrations conveying a good idea of their general arrangement.

Fig. 148 is a perspective elevation of Messrs. Hayward-Tyler & Co.'s piston-pump, and fig. 149 a similar view of the Worthington piston-pump. It will be noticed that neither illustration shows a condenser, which, for underground purposes, is indispensable.

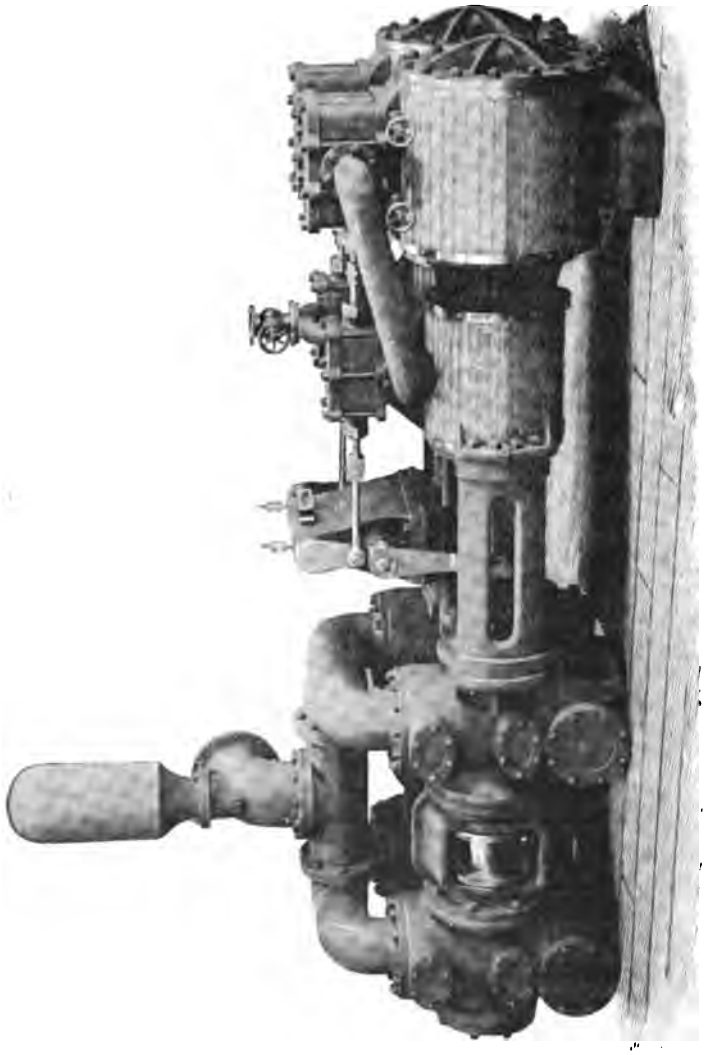


FIG. 151.—The Worthington Compound Plunger-Pump (Compound Duplex).

4. TWIN COMPOUND STEAM-CYLINDER, EXPANSIVE, CONDENSING ENGINES, WORKING DOUBLE-ACTING PLUNGER-PUMPS.

Compound Duplex Pumps.

Of the four examples illustrated, figs. 150 and 151 have what is known as 'outside centre-packed' plungers similar to those used in connection with simple pumps. Figs. 152 and 153 show the plungers packed at the ends of the pump-barrel.

Fig. 150 is a perspective elevation of Messrs. Hayward-Tyler & Co.'s plunger-pump. Fig. 151 is a similar representation of the Worthington plunger-pump; both these show a double-acting plunger packed at the centre. In figs. 152 and 153 we have views of Messrs. Tangyes' pump and the Knowles pump respectively. In these pumps there are two single-acting plungers, working in a pump-barrel with a central partition and delivering from their inner ends, and packed as already stated.

Fig. 154 is from a drawing representing the 800-feet pump-station of a mine, with an engine of this class—the Knowles—in place, and the sinking pump in position below the station. In deepening the shaft the sinking pump is lowered at intervals as the excavation progresses, the water at the bottom of the shaft being delivered to the tank or sump that supplies the pumping engine in the station. A single steam-pipe down the shaft supplies both the main engine and sinking-pump. The exhaust-steam from the former is condensed by the independent air-pump and jet condenser; that from the latter, however, is usually carried to the sump or into a special connection arranged on the suction nozzle of the pump. This connection is a neat and inexpensive condensing arrangement (not shown in the figure), and does away with the exhaust steam-pipe in the shaft.

With a pumping plant similar to that described, mines can be sunk to great depths, or flooded mines recovered with facility and security. For mines of extreme depth it has been found advisable to put pumping stations at every 500 to 600 feet, although this distance can be increased to 800 to 1,000 feet when desired. By this system of pumping in stages, which is similar in principle to the Cornish pump-lifts, the main engine in the lower station delivers to the next above (which is a duplicate of the same) and so on to the surface. Below the lowest pump station is placed the sinking-pump, as referred to above. Generally these sinking-pumps are duplicated for convenience and security.

PLATE XII.

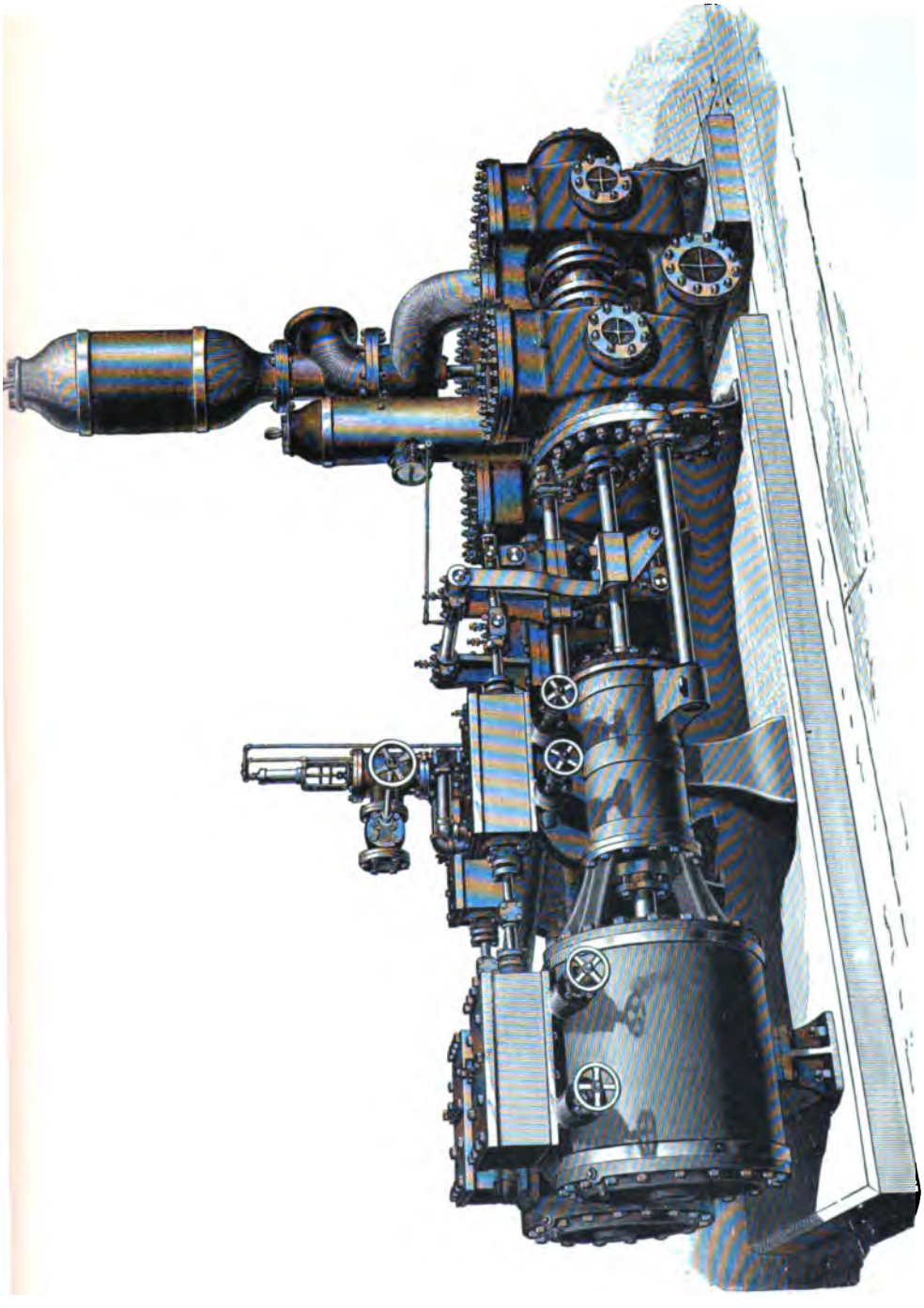


FIG. 150.—Hayward-Tyler & Co.'s Compound Duplex Plunger-Pump.

[To face p. 240.

PLATE XIII.

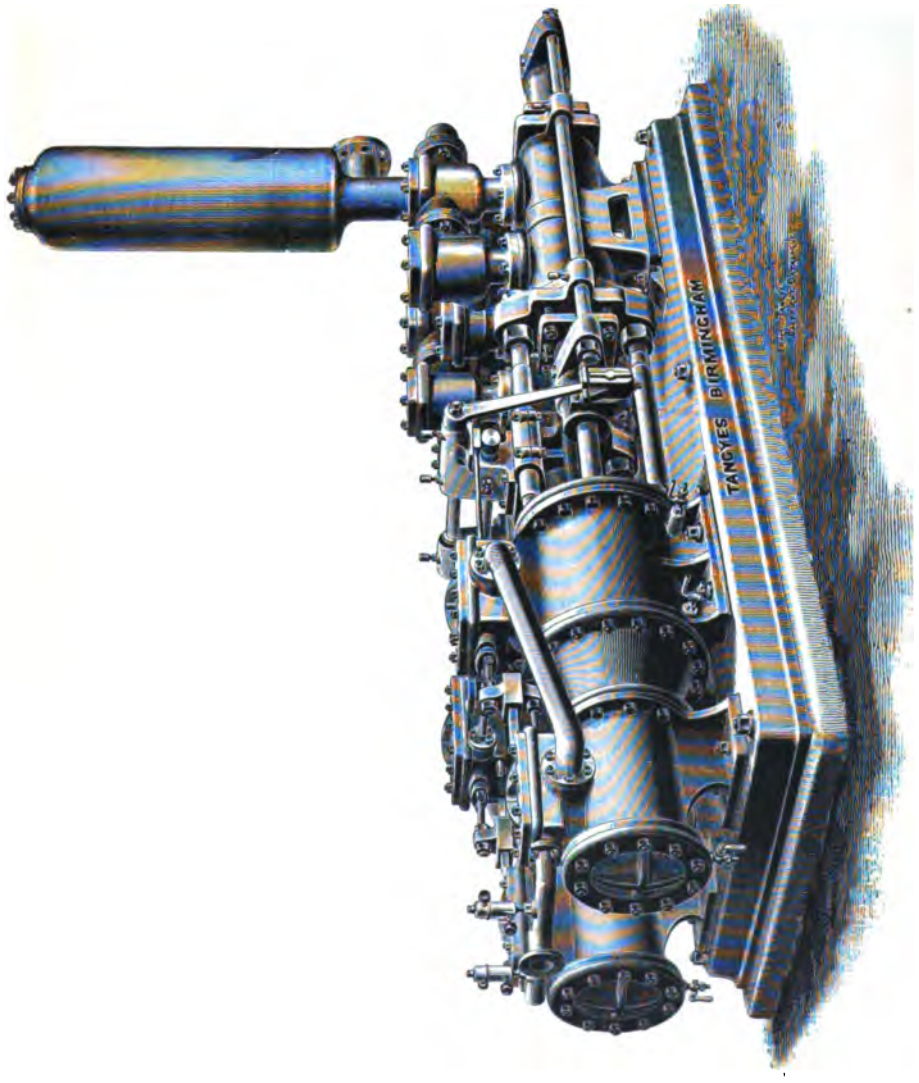


FIG. 152.—Tangye's Compound Duplex Plunger-Pump.

[*To face p.* 240, *after Plate XII.*

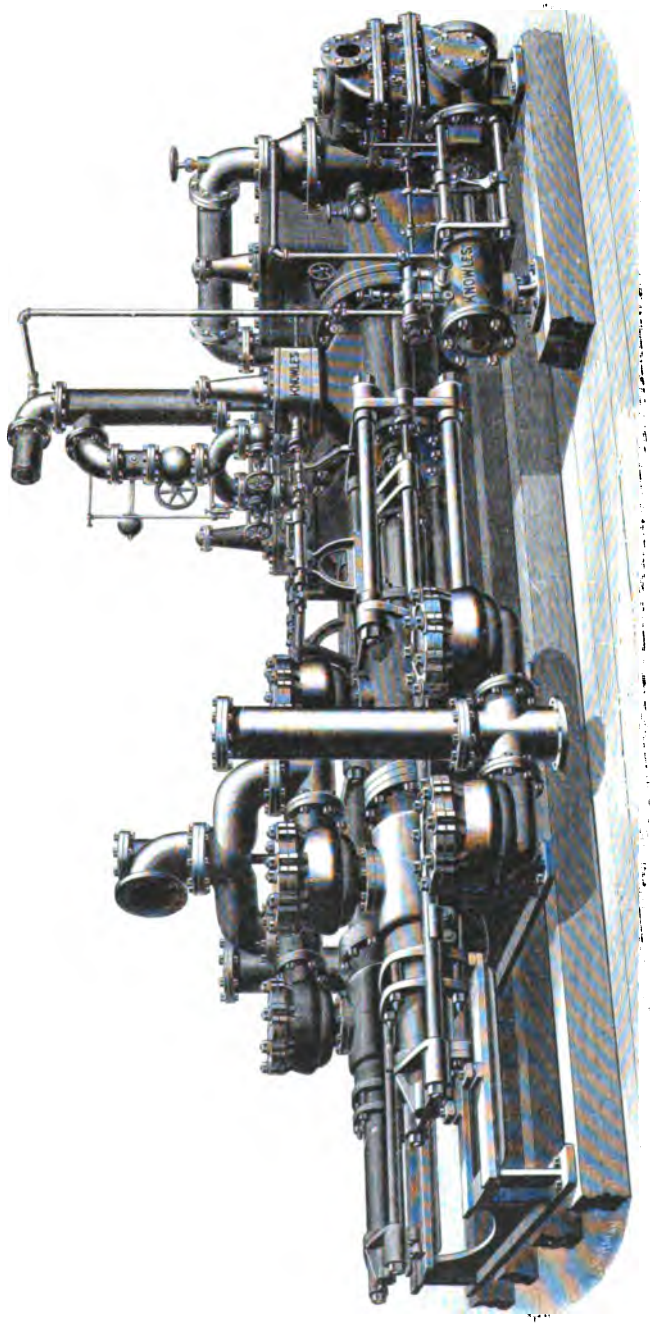


FIG. 153.—The Knowles Compound Duplex Plunger-Pump.

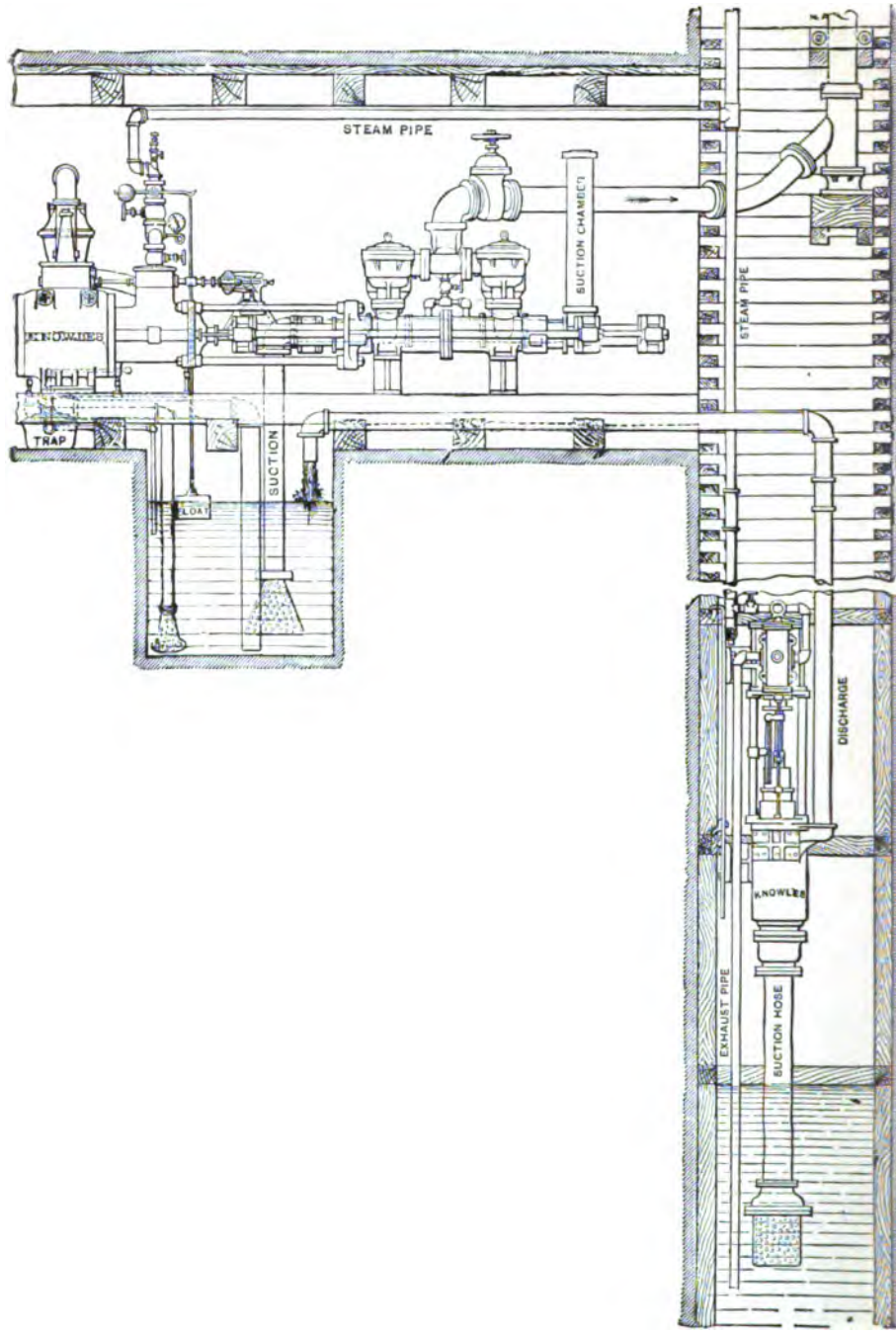


FIG. 154.—The Knowles Compound Duplex Plunger-Pump; Elevation showing Engine, with Independent Air-Pump and Condenser located in a Pump Station, complete with connections and Sinking Pump below.

C.—TRIPLE-EXPANSION STEAM-PUMPS.

In the classification of engines given at page 26 three types of triple-expansion engines are enumerated. As they are from a mining standpoint not numerically important, it will scarcely be worth the while to deal with them seriatim. The number of engines of either of the types named, or indeed of the whole of them in use underground, appears to be very limited. We doubt very much the wisdom of any further extension of the expansive principle than that embodied in the compound engine for underground service.

It is quite a moot point whether the increased economy that can be got out of a triple-expansion engine over a compound engine is a sufficient justification for the extra cost involved, the additional excavation space required underground, and the greater complication of parts, and, therefore, increased liability to injury and disablement. It is, of course, a well-recognised axiom that under equal conditions the compound engine must yield the palm for economy of steam to the triple-expansion engine, in the same way as that must be surpassed by a quadruple-expansion engine (taking steam at a correspondingly higher initial pressure).

In order to get the full benefit of the higher range of expansion, steam of largely increased pressure is essential; the pressures used vary from about 100 lbs. per square inch—which in ordinary cases may be taken as the minimum useful pressure—to about 180 lbs. or even 200 lbs. per square inch.[1] For marine and waterworks purposes and for other services at surface the triple-expansion engine in one form or another is extensively used and to great advantage, very high duties being achieved. The steam consumption varies, according to the design of the engine and the circumstances of its use, from about 11·75 to 16 lbs. per indicated horse-power per hour, or, say (assuming the evaporative power of the coal at 9 lbs. of water per pound of coal), from 1·3 to 1·8 lb. of coal. 'The best reliable results obtained with a triple-expansion engine are those of the Allis engine at Milwaukee, where the consumption, when indicating 574 horse-power, was 11·68 lbs. (of steam) per indicated horse-power per hour, the steam pressure being 120 lbs. per square inch. Ordinary triple-expansion engines give, however much less satisfactory

[1] Here, as elsewhere throughout this work, the pressure given is 'absolute.' Boiler pressures, as shown by the steam-gauge, are expressed in pounds per square inch above the atmosphere. What is known as 'absolute' pressure is the gauge pressure added to that of the atmosphere, which may be taken as 14½ lbs. as an average. If, for example, the gauge pressure is 109·75, we have for the absolute pressure 109·75 + 14·50 = 124·25 lbs. —S.M.

results, the best showing in the case of the marine engines reported on by a committee of the Institution of Mechanical Engineers, being 13·35 lbs. per indicated horse-power per hour, the boiler pressure being 179·58 lbs. per square inch.'[1]

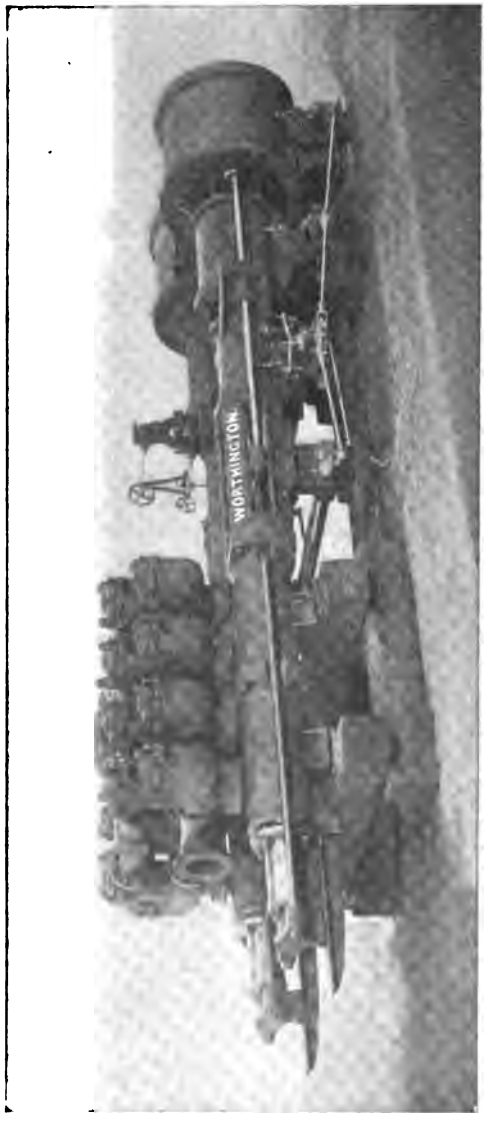


FIG. 155.—The Worthington Triple-Expansion Plunger-Pump.

Fig. 155 is an elevation of the Worthington Triple-Expansion Mine Pump, with outside-packed plungers.

[1] *Engineering*, October 9, 1896, p. 469.

D.—SINKING STEAM-PUMPS.

Very few sinking pumps of the horizontal type are in use. Only two or three examples have come under the author's notice, and one of these

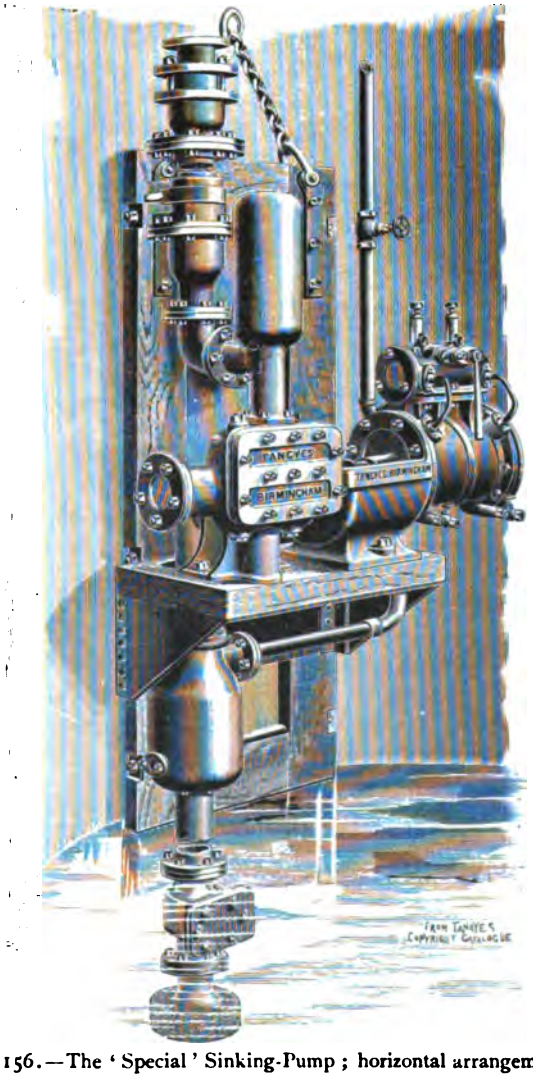


FIG. 156.—The 'Special' Sinking-Pump; horizontal arrangement.

was abandoned as impracticable; the horizontal arrangement requires too much space transversely in the shaft to make their use possible, except in cases where space is no object, such as in quarries and other open workings. The vertical pumps, considered at length in another section of this work, are much better adapted for the purpose, as the room they take is chiefly in a direction where space is no object.

Fig. 156 represents the 'Special' sinking-pump, bolted to a timber frame or staging, and fitted with Floyd's Exhaust Steam-Condenser.

II.

VERTICAL PUMPING ENGINES

A.—ROTARY VERTICAL ENGINES.

THESE engines are very useful for feeding boilers, supplying tanks, for factories, marine, and other purposes; but they are not so extensively used for underground mine drainage as those of the horizontal class, and are not made in such large sizes. Compared with horizontal engines of the same class their principal recommendation for underground operations is the small space required transversely, which makes them very useful for small shafts and other places where it is not practicable, without a considerable expenditure in excavations, to use a horizontal pump.

All the purposes to which the simple horizontal engines are applied can be served by engines of this class, but engineers generally prefer, under ordinary circumstances, to use a horizontal engine, and a non-rotary to a rotary, as we have already had occasion to remark. Having in the same place (pp. 31 and 32) enumerated the merits and demerits of engines of the rotary type, it will now only be necessary to state that these engines are usually very compact and solidly made. There is less wear with the steam-piston than is the case with horizontal engines. The pump is generally of the plunger type, the plunger being packed by an outside stuffing-box.

There are various combinations of single-acting and double-acting rams, as enumerated in the Classification at page 26. The principle of compound steam-cylinders has been adopted in a few instances, but this must detract from the portability and compactness of the machine, and we question the wisdom of compounding for such comparatively small engines. Of course, where the circumstances necessitate the use of a large pump of this type the economy of the compound principle might make it worth the while to adopt it. When desired, a condenser can be supplied to any of the double-ram pumps.

These pumps may be made of any required strength and for pumping under any of the conditions to which other classes of underground pumps have been applied, adapting them for the deepest and most extensive drainage operations

With the aid of the illustrations the reader will be able very readily to understand the general construction of the various types of these pumps. In the simple class the steam-cylinder is mounted upon a pair of cast-iron

columns which act as delivery air-vessels to the pump. The steam-cylinder is fitted with an ordinary three-ported slide-valve, which is worked direct from an eccentric on the crank shaft. The pump-ram, which is outside-packed, is cast with a triangular piece forming the vibration loop, within which the lower end of the connecting-rod oscillates. The piston-rod is cottered to the upper end of the loop, and a little below is the wrist pin for the small end of the connecting-rod. The crank-shaft is supported at one end by brackets cast with the aforesaid columns and by a stand at the other end. The suction and delivery branches are at the lower part of the pump; the suction and delivery valve-chambers are arranged directly under the air-vessel. The bed-plate is hollow and acts as an air-vessel and a reservoir for the water. Figs. 158, 159, and 160 are examples of this class.

In some forms the crank-shaft is under the pump, and the fly-wheel consequently fixed almost at the bottom of the engine. The vibration-loop takes hold of the piston-rod and ram in a different manner from other kinds of engines, and being so long the side-thrust due to the crank is inconsiderable. The advantage of the fly-wheel so low down is that the engine is steadier, and even very large engines require no foundation-bolts. The arrangement is less compact than the first form named, and is not suitable for underground use.

Single-ram double-acting pumps are provided with an additional ram-case and set of suction and delivery-valves. The ram-cases are fixed over each other: the ram is attached to a small rod which works through a stuffing-box at the top of the upper ram-case, the ram itself passing through two stuffing-boxes. In the variety shown at fig. 160 the ram is much shorter than in the ordinary type and works through one stuffing-box only.

In other varieties of pumps double action is secured by a combination of two single-acting rams, as in figs. 161 to 166. It will be observed that the two pumps are bolted upon the same bedplate, and that the columns or pillars supporting the steam-cylinders are cast with brackets and square flanges as in the single-ram pumps, to which the cylinder bottoms are bolted. The fly-wheel works between each pair of columns, operating cranks set opposite to each other, so that when one pump draws the other forces. The suction passage is common to both pumps. It will be seen that engines of this class are very compact and occupy little space. Maintaining a uniform delivery and working more smoothly than the single-ram pumps, they are much better adapted for dealing with large quantities of water and great pressures.

The principle of multiple action has been carried a stage further by combining two double-acting ram-pumps in one machine, in a similar manner to the duplication of single-acting pumps just described. Figs. 167 and 168 are examples of this class.

For further information on the construction of the various types of pumps the reader is referred to the detailed descriptions which follow.

The diagrams shown at fig. 157, which are reduced from those

courteously supplied to the author by Mr. Charles Sadd, of Holme, Westmorland, will be of interest and utility to persons considering the selection of pumps of this class for mining purposes, as illustrating graphically the relative fluctuation of flow in various kinds of pumps, and demonstrate the necessity and value of air-vessels.[1] The great inequality of flow of single-ram pumps and of double-ram pumps when worked at 'quarter centres' instead of 'opposite centres' is apparent, as is also the exceptionally uniform discharge of three-ram pumps. The latter, however, owing to their greater cost, do not meet with much favour. It has already been remarked at page 72 how important it is that pumps should be supplied both on their suction and delivery pipes with air-vessels. Those remarks may well be supplemented by the following by Mr. Sadd:[2] 'Sometimes the momentum of the water in the suction-pipe is sufficient to create a positive pressure, and consequent shocks and vibration when met by the piston or ram, or when the inlet-valve is quickly closed against it; the soothing influence of an air-vessel in such a case is evident. Where the suction draft is great, an air-vessel, if charged with air, tends to increase the efficiency of the pump by more completely filling it at each stroke, and so reducing the shocks which occur when it is not perfectly full. It is an excellent plan to fit these vessels with gauge-cocks or glass gauges, similar in principle to those usually attached to steam boilers, so that it may be better known to what extent they are charged with air. Air-vessels should be larger as the variation of flow is greater (see diagram); further, for any given size they will be more efficient as the variation of flow is less. It is essentially necessary in every case that air-vessels should not only be large enough, but also sufficiently charged with air.'

Referring to the diagrams, Mr. Sadd remarks:

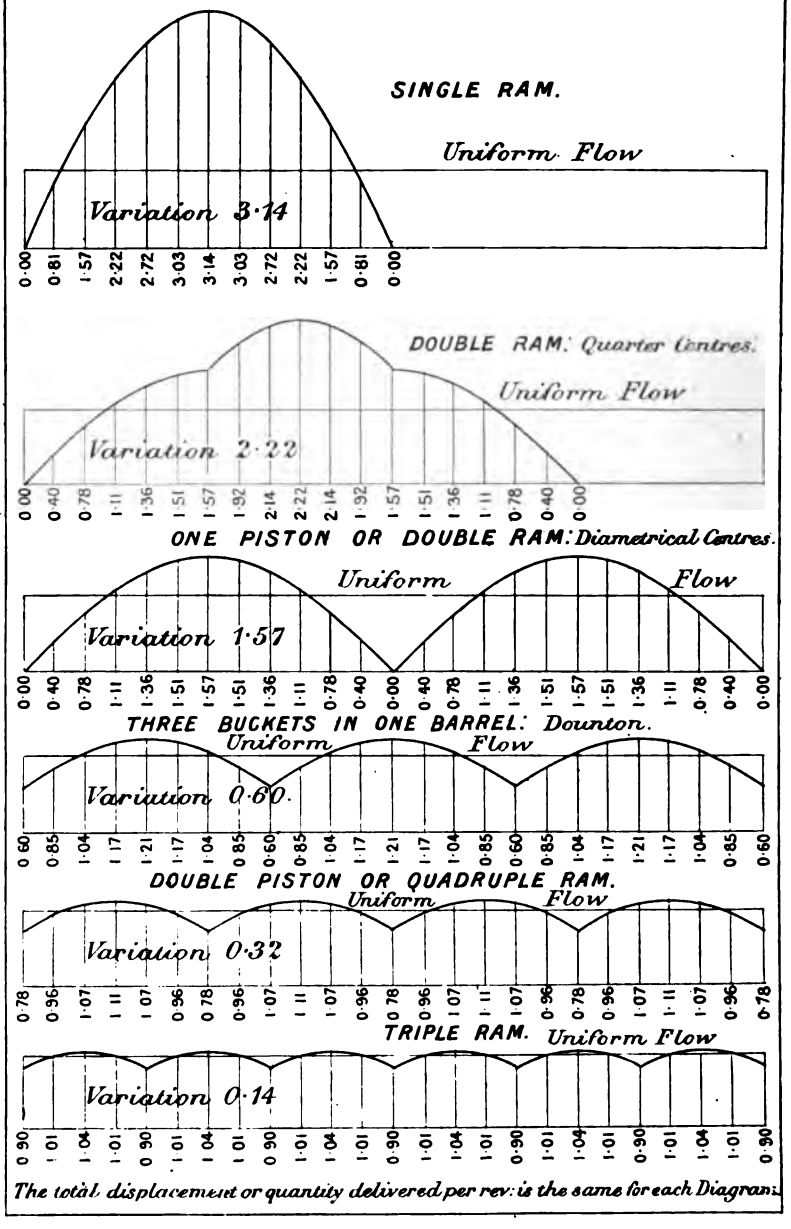
'The diagrams showing the variation of flow are equally applicable to horizontal and vertical pumps which are controlled by fly-wheels. The curves illustrate the theoretical variation of discharge from the various classes of pumps represented, and are intended to show the relative necessity for the use of air-vessels, in order to obtain in each example the maximum equality of flow from the reciprocating rams or pistons. The speed of rotation is assumed to be equal and uniform in every case, and the conditions of working such as will cause the water to completely fill the pump at each stroke.'

'It will be seen by inspection that the length of each diagram embraces one entire revolution of the crank-shaft, and that the areas contained between the horizontal lines marked 'uniform flow' and the datum lines are all equal, and indicate the average or mean discharge for one revolution. The areas included between the curves and the datum lines are also equal, but their form indicates the number, order, and extent of the successive

[1] The *Artizan*, August 1, 1858, p. 187, discussed this subject at some length, and gave similar diagrams to those of Mr. Sadd.

[2] Letters to Author, dated December 22 and 31, 1897.

Fig. 157. **VARIATION OF FLOW WITH UNIFORM SPEED OF ROTATION.**



The total displacement or quantity delivered per rev: is the same for each Diagram.

variations. The figures give the numerical variation in relation to the mean flow taken as unity.'

'In every case the flow can be made nearly uniform by the use of efficient air-vessels, providing they are large enough and kept charged with air; but the advantages of greater uniformity in the natural flow from the pump and less dependence on the air-vessels are obvious; moreover, a steam-pump with a single 7-inch ram will deliver nearly the same quantity of water as one with two 5-inch rams running at the same speed, but the single ram-pump will require a much larger or heavier fly-wheel to control it on account of the greater inequality of flow.'

A.—SIMPLE STEAM-PUMPS.

Description.

These engines are often known as 'donkey-engines,' and are applied to a great variety of purposes. The smaller kinds are extensively used in the navy for feeding boilers and pumping out water ballast and bilges, whilst in chemical works, tanneries, gas-works, breweries, etc., they find an unlimited sphere of usefulness, although perhaps not so largely employed as the non-rotary horizontal pumps. They are usually restricted to a small size, but for mining purposes are made sometimes as large as 25-inch steam-cylinders and from 15 to 18-inch rams.

For a detailed explanation of their construction the reader is referred to the descriptions given of the various engines in the following pages.

Sizes, Weights, and Speed.

Sizes.—These pumps are made in sizes varying from 4-inch to 25-inch steam-cylinders, and from 2-inch to 18-inch pumps, and from 4-inch to 18-inch stroke, but the principle is of course not limited to these sizes. Only the larger sizes are of any service for mine drainage.

Weights.—The accompanying tables give some information on the weight of pumps of this class. They are much lighter than rotary horizontal engines of the same capacity owing to their not requiring such an extended bedplate.

Speed.—Owing to the stroke being limited by a crank, these pumps can be worked at their highest speed with safety, and through the regulating and compensating medium of a heavy fly-wheel there is great regularity in the strokes. As the steam-valve is operated by the certain and unerring movements of an eccentric on the crank-shaft, no erratic action of the valve can ensue, and the steam may be cut off at any portion of the stroke with the greatest exactitude; a saving of steam is thus effected.

Capabilities.

The best forms of vertical pumps of the rotary class, such as those of Mr. John Cameron, Frank Pearn & Co., Ltd., Elijah Ashworth, and similar pumps of other makers, may be applied to the deepest and most extensive

drainage operations performed by any other class of simple steam-pumps. In one large colliery district in South Wales which the author visited, pumps of this class were reputed to be the favourites.

Mr. Cameron has supplied to Jones's Navigation Colliery, Rhondda Valley, South Wales, a 3-inch double-ram pump, with two 11-inch steam-cylinders, to force to 1,125 feet. A great number of Mr. Cameron's pumps are in use in deep pits, forcing up to 1,200 feet vertically. An extra strong 'Simplex' quadruple-acting ram-pump, with two 25-inch steam-cylinders, two $4\frac{3}{4}$-inch rams and 9-inch stroke, to force water 1,200 feet in a single vertical lift, has been supplied to a Welsh colliery, and Messrs. Hulme and Lund have made for a Lancashire colliery a small pump to force to 1,140 feet in one lift.

For situations where the lift is comparatively low, say not exceeding 100 feet, a single-ram is more simple, and has the advantage of costing much less than an ordinary double-ram pump for a given quantity of water raised. Such a pump has been found useful in forcing water through drifts into a sump, from which it is raised by a larger and more powerful engine.

In low galleries, small levels, and in any workings which have very little vertical space, engines of the horizontal type are more suitable, but this is a circumstance that cannot militate much against the adoption of vertical engines in mines and collieries for general light drainage.

Mr. Cameron has made his double-ram pumps in sections suitable for taking down a shaft, and they are easily put together by an ordinary workman. They have been made for forcing water in coal-pits 1,500 feet in a single column. The largest made had 18-inch rams with 18-inch stroke, and weighed about 27 tons. It enabled the owners of the colliery to stop a large beam-engine, and has worked several years satisfactorily.

Mr. Cameron has supplied pumps of the design shown at fig. 164 (double-ram type) to a great many collieries in this country and abroad. Two $9\frac{1}{2}$-inch double-ram pumps, $10\frac{1}{2}$-inch stroke each pump, fitted with two 24-inch steam-cylinders, were made for the Wigan Coal and Iron Company. The first pump was supplied in 1883, and the second in 1887. Each pump had to discharge 250,000 gallons in twenty hours against a head of 762 feet with 60 pounds steam-pressure at the boilers. An 8-inch double-ram pump, $10\frac{1}{2}$-inch stroke, with two 24-inch steam-cylinders, to force water against a head of 750 feet with 35 pounds steam- or air-pressure, was delivered in 1887 to the Whitburn Coal Company, Ltd., Marsden, South Shields. A $12\frac{1}{2}$-inch double-ram pump, 14-inch stroke, with 30-inch steam-cylinders, to discharge 25,000 gallons per hour against a head of 450 feet, with 35 lbs. steam-pressure, has been sent to the Equitable Mine, near Calcutta.

Several large pumps of this type have been supplied to ironworks. Three 20-inch double-ram pumps, 18-inch stroke, with 17-inch steam-cylinders and governor, were made for Messrs. Bell Brothers, Middles-

brough. One 23-inch double-ram pump, 18-inch stroke, with 22-inch steam-cylinders and governor (the steam-cylinders being fitted with Meyer's expansion-valves), went to Messrs Cochrane & Co., Ormesby Furnaces, Middlesbrough. Four 24½-inch double-ram pumps, 18-inch stroke, each pump fitted with two 19-inch steam-cylinders, governor, and Meyer expansion-valves to steam-cylinders, were supplied to the North-Eastern Steel Company, Ltd., Middlesbrough, and others to various firms.

Pumps of the quadruple-acting class (two double-acting rams) have been designed for working against great pressures in mine-lifts, 400 pounds per square inch and upwards.

The first and second tables give the dimensions and capacities of single-ram pumps and double-acting pumps (two single-acting rams) respectively, manufactured by Mr. John Cameron. The third table enumerates some of the sizes of quadruple-acting pumps (two double-acting rams) of Messrs. Frank Pearn & Co., Ltd.

Dia. of steam cyl.	Dia. of ram	Length of stroke	Revs. per min.	Water per hour	Dia. of suction pipe	Dia. of delivery pipe	Dia. of stm. pipe	Dia. of exhaust pipe	Total height		Width: Over pipes		Width: Front to back		Weight
in.	in.	in.		gallons	in.	in.	in.	in.	ft.	in.	ft.	in.	ft.	in.	cwts.
6	3	5	90	670	2	1½	¾	1	5	1	3	2	2	0	9
6	3½	5	90	900	2½	2	¾	1	5	1	3	2	2	1	10
7	4	6	80	1,280	2½	2	¾	1¼	5	8	3	6	2	5	14
7	4½	6	80	1,600	3	2½	¾	1¼	5	11	4	0	2	8	17
7	5	6	80	2,000	3	2½	¾	1¼	5	11	4	0	2	8	18
7	5	7	75	2,170	3	2½	¾	1¼	6	5	4	3	2	10	20
8½	6	6	80	2,880	3½	3	1	1½	6	3	4	6	3	1	25
8½	6	8	70	3,200	3½	3	1	1½	7	2	4	8	3	1	28
10	7	7	75	4,000	4½	3½	1¼	1¾	7	5	5	4	3	4	40
10	7	9	60	4,400	4½	3½	1¼	1¾	8	3	5	5	3	4	43
12	8	8	64	5,400	5	4	1½	2	8	2	5	9	3	6	50
12	8	10	54	5,750	5	4	1½	2	9	1	6	0	3	6	54
14	9	9	60	7,250	5½	4½	2	2½	8	11	6	0	4	0	65

Dia. of steam cyl.	Dia. of ram	Length of stroke	Revs. per min.	Water per hour	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Total height		Width: Over pipes		Width: Front to back		Weight
in.	in.	in.		gallons	in.	in.	in.	in.	ft.	in.	ft.	in.	ft.	in.	cwts.
10	7	7	75	8,000	5	4½	1½	1¾	7	5	5	9	4	7	64
10	7	9	60	8,800	5	4½	1½	1¾	8	3	5	9	4	7	67
12	8	8	64	10,800	6	5	2	2	8	2	6	3	5	2	83
12	8	10	54	11,500	6	5	2	2	9	1	6	6	5	2	87
14	9	9	60	14,500	7	5½	2½	2½	8	11	6	6	5	7	103
14	10	10	54	18,000	7⅓	6	2½	2½	9	8	7	3	6	0	126
15	10	12½	47	20,000	7½	6	3	3	10	9	7	7	6	0	142
17	12	12	47	24,000	9	7½	3½	3½	11	0	8	4	6	9	198
17	12	15	40	28,800	9	7½	3½	3½	12	5	8	9	6	9	214
21	15	15	35	40,000	11	9	3½	3½	13	0	9	9	7	4	290
25	18	18	30	58,000	13	11	4	4	15	3	11	9	9	2	

Dia. of steam cyl.	Dia. of ram	Length of stroke	Revs. per min.	Water per hour	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Total height	Width: Over pipes	Width: Front to back	Weight
in.	in.	in.		gallons	in.	in.	in.	in.	ft. in.	ft. in.	ft. in.	cwts.
12	9	9		27,000	8	8	2½	2½	8 10	4 10	5 0	75
12	10	9		30,000	9	9	2½	2½	8 10	4 10	5 0	80
12	10	10		31,000	9	9	2½	2½	9 9	5 0	5 6	100
14	11	10		40,000	10	10	3	3	9 8	5 3	5 6	110
16	11	12½		46,000	10	10	4	4	11 3	6 3	6 3	160
16	12	12½		50,000	12	12	4	4	11 3	6 3	6 3	170
16	12	15		55,120	12	12	4	4	12 6	7 0	7 0	240
18	13	15		59,000	12	12	4	4	12 6	7 0	7 0	260
20	14	15		66,000	12	12	4½	4½	12 9	6 10	7 0	280

Cost.

By comparing the prices on the next page with those of the non-rotary pumps, it will be found that the single-ram double-acting pumps are slightly more costly than non-rotary pumps of a similar size, and that the double-acting ram-pumps with two rams cost from about 30 to 65 per cent. more than corresponding non-rotary pumps. The lists include a variety of ram-pumps by different makers. About 10 per cent. extra is charged for governors, etc., for small, and about 5 per cent. for large engines. The first six pumps have brass-cased rams.

The apparent discrepancy between the capacity of pumps in one group and those of the same size in another is due to the makers basing the delivery upon a different piston-speed. For instance, the delivery of the 10 × 6 × 8 pump in the first group is calculated at 70 revolutions a minute, whereas that of the same size pump in the next group is based at 75 revolutions. At, say, 40 lbs. steam-pressure the engines enumerated are suitable for 'heads' varying from 100 to 370 feet, according to the ratio of the steam-cylinder or cylinders to the ram or rams, *e.g.*, a 14 × 7 × 10 engine would force to 370 feet; a 14 × 12 × 10 only to 125 feet.

1. SINGLE STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES, WORKING DOUBLE-ACTING PISTON-PUMP.

Engines of this type are not suitable for general underground drainage; their use is restricted to boiler-feeding and other purposes in factories, vessels, etc.

2. SINGLE STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES, WORKING ONE SINGLE-ACTING RAM-PUMP.

Cameron's Single-Acting Ram-Pump.

This admirable steam-pump was invented by Mr. John Cameron, of the Oldfield Road Iron Works, Salford, Manchester, in 1853, and is perhaps the oldest and best-known engine of the class in use.

SINGLE-ACTING PUMPS

One-ram

Dia. of steam cyl.	Dia. of ram	Lgth. of stroke	Water per hour	Price	Dia. of steam cyl.	Dia. of ram	Lgth. of stroke	Water per hour	Price
in.	in.	in.	gallons	£	in.	in.	in.	gallons	£
6	4	4	1,120	31½	12	6	8	3,600	58
7	5	5	1,800	40	12	8	8	6,400	64
7	5	6	2,000	41	14	7	10	4,900	102
7	5	7	2,170	42	14	9	10	8,100	107
8½	6	6	2,880	49½	14	12	10	14,400	114
8½	6	8	3,200	53½	16	10	10	10,000	128
10	6	8	3,200	78	16	12	10	14,400	135
					16	14	10	19,600	143
6	4	5	1,305	26					
7	5	6	2,295	35					
8½	5	6	2,295	40					
8½	6	8	3,600	50					
10	6	8	3,600	52					
10	9	8	8,100	61					

DOUBLE-ACTING PUMPS

One-ram

Dia. of steam cyl.	Dia. of ram	Lgth. of stroke	Water per hour	Price
in.	i.	in.	gallons	£
10	8	9	10,200	100
12	9	9	13,800	120
12	10	9	15,000	128
12	10	10	15,000	137
14	11	10	20,000	157
16	11	12½	23,000	187
16	12	15	27,560	220
18	13	15	29,000	236
20	14	15	33,000	265

Two-rams

Dia. of steam cyl.	Dia. of ram	Lgth. of stroke	Water per hour	Price
in.	in.	in.	gallons	£
10	7	9	8,800	113
12	8	8	10,800	134½
14	9	9	14,500	172
14	10	10	18,000	210
15	10	12½	20,000	231
17	12	12	24,000	283½
17	12	15	28,800	315
14	9	10	16,200	188
14	10	10	20,000	195
14	12	10	28,800	210
16	10	10	20,000	224
16	12	10	28,800	238
16	14	10	39,200	252

QUADRUPLE-ACTING PUMPS

Two-rams

Dia. of steam cyl.	Dia. of ram	Lgth. of stroke	Water per hour	Price
in.	in.	in.	gallons	£
10	6	8	11,840	130
10	7	8	16,000	140
10	8	9	20,480	189
12	9	9	27,000	230
12	10	9	30,000	235
12	10	10	31,000	245
14	11	10	40,000	278
16	11	12½	46,000	330
16	12	12½	50,000	365
16	12	15	55,120	420
18	13	15	59,000	455
20	14	15	66,000	510

Since its introduction it has been gradually improved ; the engine shown in the annexed illustration, fig. 158, which was patented, is one of the latest developments of the principle.

This engine consists of a steam-cylinder with an ordinary three-ported

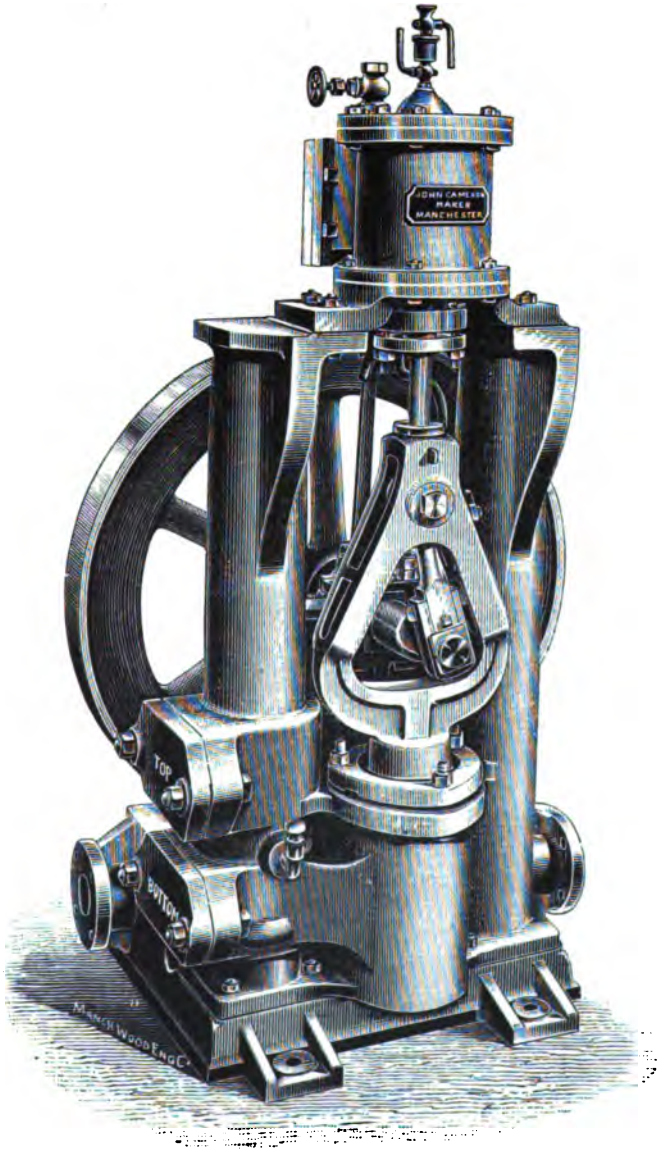


FIG. 158.—Cameron's Single-Acting Ram-Pump.

slide-valve, worked direct from an eccentric on the crank-shaft, and mounted on two cast-iron columns, which serve as delivery air-vessels to the pump.

It will be observed that the columns, the valve-chambers, and the ram-case are one casting, which is bolted to the bedplate, and that the cylinder-bottom is secured to the top of the columns by means of bolts.

The vacuum-vessel and suction-branches are cast on the bedplate, which contains a water passage communicating with the valve-chamber. It has been found that this arrangement affords greater facilities for repairs or the replacement of any part which might be found to be defective or become injured than the design in which the cylinder, columns, and bedplate are cast together in one piece, as at one time made by Mr. Cameron.

The arrangement of the water part is very simple. Upon the end of the ram, and forming part of the same casting, is a triangle, to the top end of which a piston-rod is cottered, and a little below this is the wrist-pin for the small end of the connecting-rod.

The fly-wheel is mounted upon a shaft, supported upon a bracket cast with the columns, at one end, and upon an A stand at the other end, which is bolted to the bedplate of the pump.

The suction and delivery valve-chambers are arranged directly under one of the delivery air-vessels, and from their position are easily accessible for examination and repair. The suction and delivery-branches are at the lower part of the pump, as shown in the illustration.

The pump-ram is cast to the bottom of the triangle, and works through a gland and packing, which is supported by a loose brass collar bush at the bottom of the stuffing-box. The ram-chamber communicates direct, by a short passage, with the pump-valves. The top or delivery-valve allows the water to pass direct into the air-vessel above, whence it flows into the second air-vessel column, where its flow is further equalised before its final exit. The suction-valve communicates direct with the vacuum-vessel of the pump, whence, on the rise of the ram, it gets its intermittent supply due to its displacement. The water taken from the vacuum-vessel is replenished by a constant flow from the well, caused by the atmospheric pressure on the water, and thus the constant flow of the water is maintained, and shocks to the suction-pipe avoided. The valves are of the ordinary mushroom class, with centre-guide spindles, and are usually of the same diameter as the pump.

Guards are fitted to the valve-doors so that the lift of the valves can be restricted, the object being to prevent any return of the water back through the valve while closing, and reduce the concussion which occurs when the lift is too high. More lift is allowed to the suction-valve than to the delivery-valve, for the reason that the water being propelled by the pressure of the atmosphere only, and opposed by the weight or counter-pressure due to the vertical height of the water in the suction-pipe, a larger

opening of the valve is necessary, in order that the water may follow the ascent of the ram and fill the barrel or ram-case. On the other hand, if the valve is allowed too much freedom it will lift so high that a portion of the water will return while the valve is closing. It is essential to the smooth working and durability of the pump that the ram-case should be as nearly as possible filled at every stroke.

Evans's Single-Acting Ram-Pump.

The construction of this pump is sufficiently evidenced by the accompanying illustration, fig. 159.

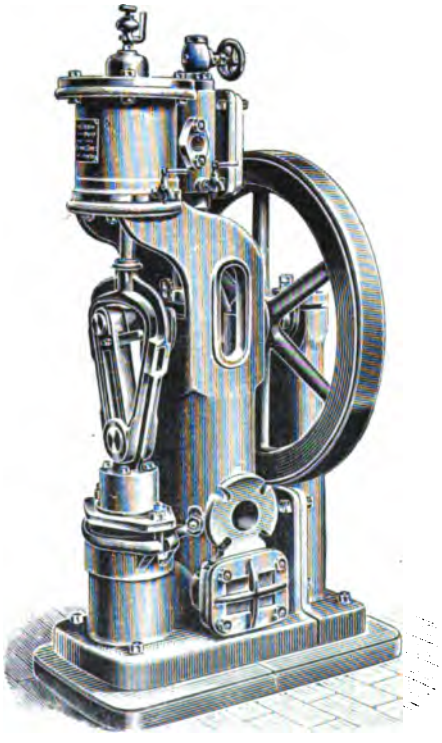


Fig. 159.—Evans's Single-Acting Ram-Pump

3. SINGLE STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES, WORKING TWO SINGLE-ACTING RAM-PUMPS.

Cameron's Double-Ram Pump.

The principle of action of this pump is precisely the same as that of the single ram-pump. There are two single-acting rams, one connected directly underneath the steam-cylinder, from which it obtains its motion in the same manner as in the pump previously described, the second ram receiving its motion from the same crank-shaft. To the top of the triangle of the second ram is a steel rod working through a guide at the top of the two columns.

The cranks are set opposite to each other, consequently one pump is delivering its water at the moment the other is receiving it. By this means the pressure on the piston is equalised at each side, and a continuous discharge is maintained in the rising main.

This form of engine is specially useful when a large quantity of water has to be raised a short distance. It would do the same work as the pump with two cylinders at less first cost, and would compare favourably with it as regards the quantity of steam used. This engine is often used in gas and chemical works for pumping different liquids at the same time. If an accident happened to one pump, the other could be kept at work.

4. SINGLE STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES, WORKING ONE DOUBLE-ACTING RAM-PUMP.

Pearn's Double-Acting Ram-Pump.

Messrs. Frank Pearn & Co., Ltd., West Gorton, Manchester, are the makers of the pump shown at fig. 160, to which has been applied Pearn's 1893 Patent System of Packing Ram. The illustration shows the pump-

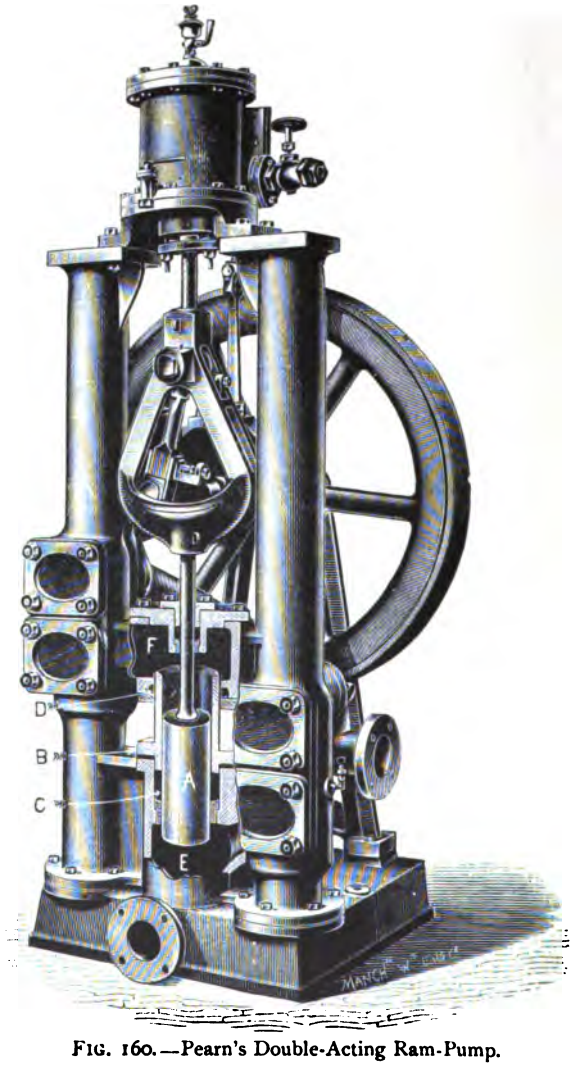


Fig. 160.—Pearn's Double-Acting Ram-Pump.

chamber in section. The ram A is of the ordinary type used in double-acting externally packed pumps, but made much shorter, as it works through one stuffing-box only instead of two, as in ordinary double-acting ram-pumps. B, the pump gland, is the novel feature in this packing, as it not only performs the ordinary function of a gland, but is in addition the pump-chamber, F, for one side of the pump. The collar for taking the gland bolts is screwed on after the gland is inserted through the top chamber, F. C is the ordinary stuffing-box, in which may be used spun yarn or any other packing. D is a joint ring to make a joint round the gland chamber B, and is slackened when the gland is required to be moved.

The great advantages of this packing are that a straight external packing is obtained in much less length than where two glands and stuffing-boxes are used. All leakage is external, and shows at once when requiring re-packing. Leakage from pump-chambers E to F is impossible. There is only one stuffing-box; this reduces friction, and causes less expense and trouble in packing. The gland is guided at each end, and cannot be twisted by screwing one side harder down than the other; thus any friction or wear due to such a cause is obviated.

Mr. Elijah Ashworth (late Ashworth Brothers), of the Moss Brook Works, Collyhurst, Manchester, is the maker of a well-known engine of this class—the 'Simplex.'

5. TWO STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES, WORKING TWO SINGLE-ACTING RAM-PUMPS.

Cameron's Patent Double-Ram Pump (two Single-Acting Rams).

This pump (fig. 161) differs from Mr. Cameron's one cylinder double-ram pump in having another cylinder, and consequently is more suitable for forcing against greater pressures. Several kinds of this description of double-ram, or two single-acting ram-pumps coupled together by steam and water-pipes and by the crank-shaft, are made. The annexed woodcut shows the class of steam-pump chiefly used for feeding boilers, and forcing water, up to 160 lbs. pressure per square inch. The two pumps are bolted upon a bedplate; the suction passage is common to both, and the cranks are set opposite to each other, so that when one pump draws the other forces. The alternate forcing action of this pump is a better method of handling water than that of the single ram-pump of the same maker. The flow of the water into and out of the pump is more regular, consequently the air-vessels produce greater regularity in the discharge. The pumping action is stated to be almost noiseless. The arrangement is compact and takes but very little room. This class is worked by one or two steam-cylinders, the one-cylinder pumps being used for pressures not exceeding 50 lbs. per square inch. Two cylinders, one above each pump-ram, reduce the pressure on the working parts one half; each cylinder, being

double-acting, does half the work. The valves have separate doors and are easy of access.

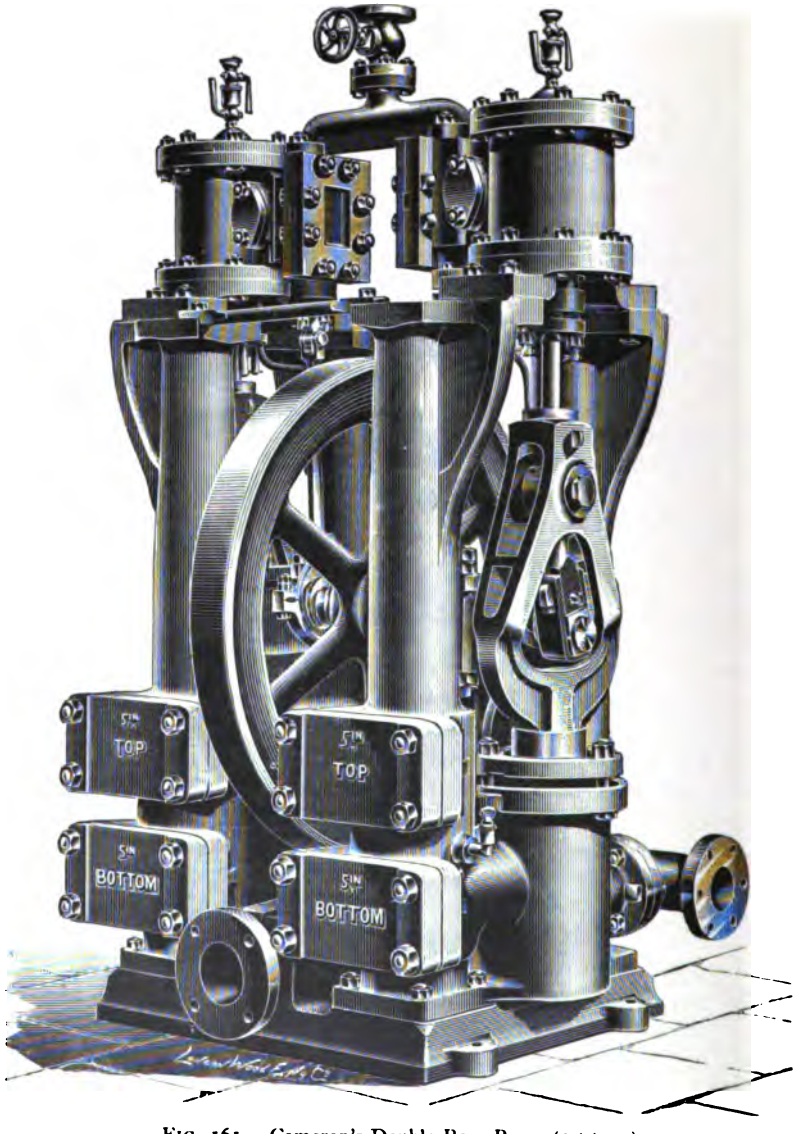


FIG. 161.—Cameron's Double-Ram Pump (1st type).

The double-ram pump shown by woodcut fig. 162 is adapted for large quantities and heavy pressures. It is used for water-works, iron-

works, chemical works, for feeding boilers, and for forcing water in coal pits in a single column up to 1,500 feet. As little standing room is re-

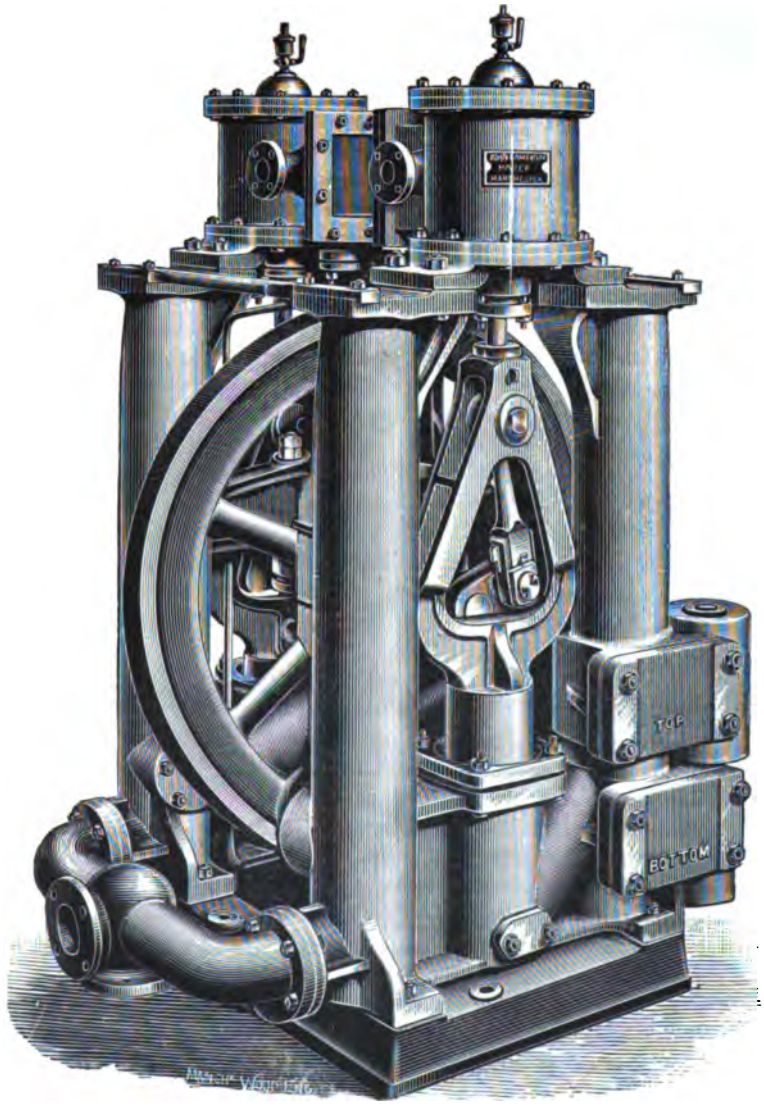


FIG. 162. -- Cameron's Double-Ram Pump (2nd type).

quired, several smaller pumps may be used and connected to the same delivery-pipe in place of one large pump, and thereby maintain a very regular water-flow up the delivery-pipe column; and in case any of them need

repacking or repair, the stoppage causes but little inconvenience. This pump is differently constructed from the two before described, inasmuch as there are no water-passages in the bedplate which, in this pump, is only a frame or plate to which the pump columns are bolted and steadily pinned, so that they are easily taken to pieces to get down pits, and as easily put together again by an ordinary workman. The largest made for forcing up a colliery shaft had 18-inch double rams with 18-inch stroke, and its weight was about 27 tons. It enabled the owners to stop a large beam engine, and has worked several years satisfactorily, forcing the water up a single delivery-column. In case of the exhaust steam being objectionable in colliery or mine workings it can, in most cases, be coupled with the suction water and condensed, and vacuum power added to the pistons by the partial removal of the pressure of the atmosphere. A governor is sometimes applied which is driven by bevel wheels, one on the crank-shaft and the other on the governor-spindle, so that in case a pipe bursts on the delivery side, or the pump draws air on the suction side, or a valve gets gagged, or from any other cause the pump is relieved of its burden, or the pressure of the steam varies, no slipping may occur, the action of the governor keeping the pump at a nearly uniform speed. The pump may be worked with considerable economy of steam by the addition of arrangements for cutting it off and working expansively, and also by attaching an air-pump and condenser.

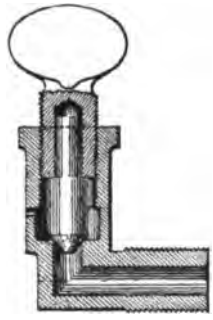


FIG. 163.

'A small pet-valve (as annexed, fig. 163) is inserted under the delivery-valve or highest part of the pump to allow egress of air or water therefrom, and so indicate its working condition. This valve is the common vertical lift-valve, and has a thumb-screw over it; on unscrewing the latter the valve acts the same as the delivery-valve of the pump, closing during the suction-stroke and preventing the admission of air which would vitiate the action of the pump. This valve was applied to vertical-acting plungers at a water-works in the year 1841 by Mr. Cameron. The pumps drew water from the River Elbe and worked all right when the tide was in, but at low water they would not draw at all, on account of the air accumulating in the plunger-cases; on the application of the pet-valve to discharge the air the reliable action of the pumps was secured. Mr. Cameron believes this was the first application of such a pet-valve to pumps. Previous to this a common small cock was, and is still occasionally, used for the purpose. The pet-valve is in almost universal use wherever known, and is a little but useful adjunct to all kinds of ram or piston-pumps.

'It will be observed on reference to the woodcuts that all the working parts are easy of access and capable of adjustment; the pumps are made throughout from a repair point of view, every important part being made

separately to gauge and template, so that in case of accident the part affected can be replaced with facility. The bearing-steps are all square-bottomed in order to "line up" easily when worn. Common head or cotter-bolts are used in preference to screws or studs for all parts that disengage, as the trouble caused by a broken stud or screw in a joint is well known to those who have had to contend with such accidents and with inferior tools.'

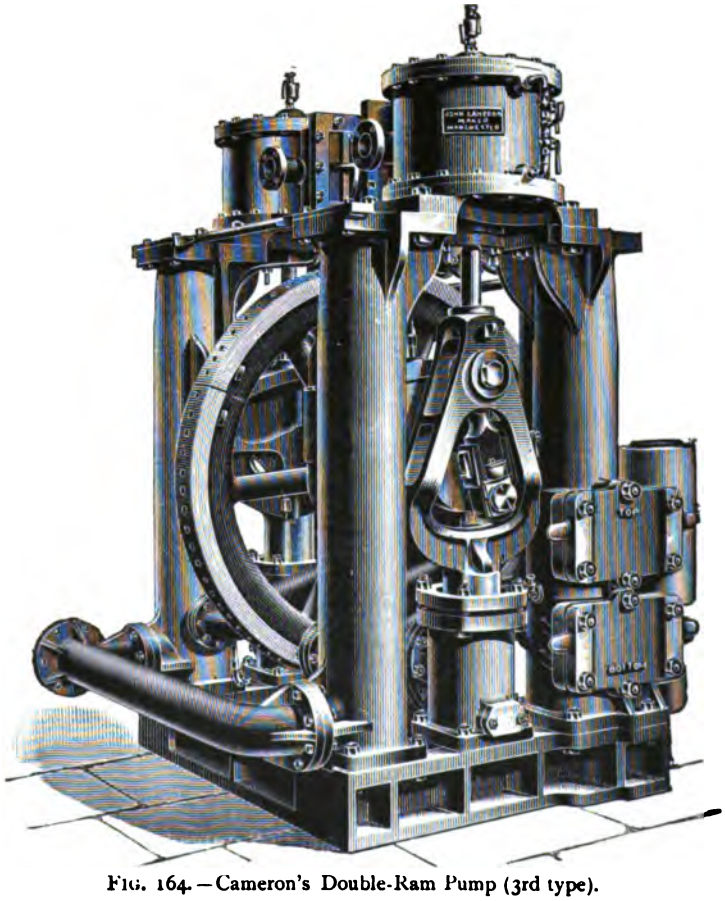


FIG. 164.—Cameron's Double-Ram Pump (3rd type).

Considerable improvements in this class of pumping-engines for mine drainage have been effected by Mr. John Cameron. In order that they may be more easily conveyed down pit-shafts and through underground workings, he now makes the large sizes with the columns and ram cases cast separately; the fly-wheels are in halves, turned and bored after being joined together; the bedplates are of a strong girder section cast in halves when the pumps are large, the joint being planed, joggled, and bolted together

(see fig. 164). Pumps made on this principle are very suitable for foreign mines, because the component pieces are more portable overland as well as underground. Furthermore, the ram-cases and columns being cast separately are more easily replaced in the event of accident, or being eaten away by impure water.

Evans's Double-Ram Pump.

Messrs. Jos. Evans & Sons, Wolverhampton, are the makers of a pump of this class, as represented by fig. 165.

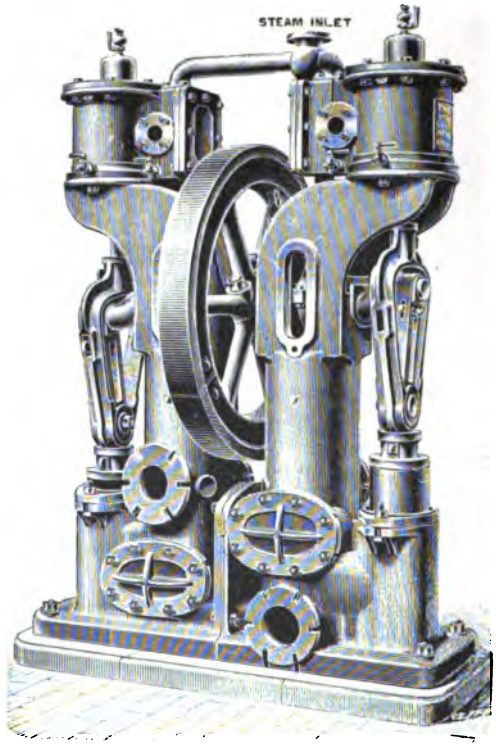


Fig. 165.—Evans's Double-Ram Pump.

Pearn's Double-Ram 'Cameron' Pump (with Condenser).

This type of pump is specially constructed for colliery work. When fitted with a condenser and blow-through valve, as shown in the illustration (fig. 166), the exhaust steam is turned into the suction and condensed, providing the proportion of the steam-cylinders to the rams is not too large. This system of condensing is very useful when there are no other means of

disposing of the exhaust. It can be made extra strong for forcing up to 1,200 feet vertical. Each valve has a separate door for easy access; all water-joints are recessed. The bearings of crank-shaft and connecting-rods

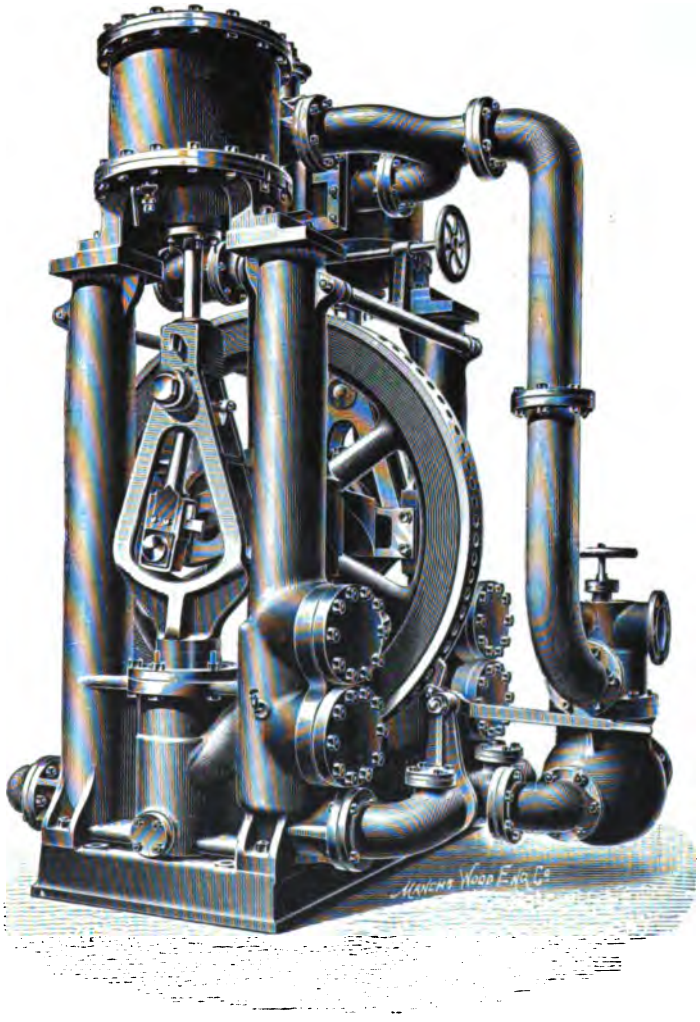


FIG. 166.—Pearn's Double-Ram 'Cameron' Pump (with Condenser).

are made of gun-metal, and are adjustable. Each pump is fitted with steam stop-valve and cylinder lubricators.

Makers, Messrs. Frank Pearn & Co., Ltd., West Gorton, Manchester.

6. TWO STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES, WORKING TWO DOUBLE-ACTING RAM-PUMPS.

Cameron's Quadruple Ram-Pump.

This pump (fig. 167) has been specially designed for working at pressures of 400 pounds per square inch and upwards. It is double-acting

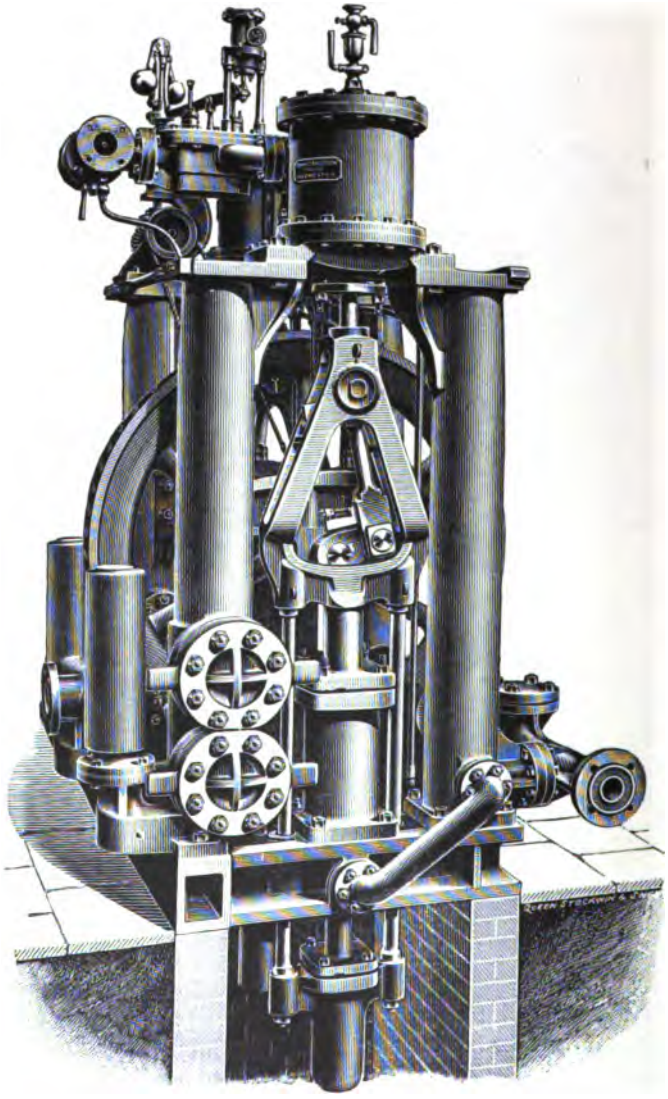


Fig. 167.—Cameron's Quadruple-Acting Ram-Pump.

on the suction side, and quadruple on the delivery. The main rams have twice the area of the auxiliary rams.

The action of the pump is as follows: On the down-stroke of the main

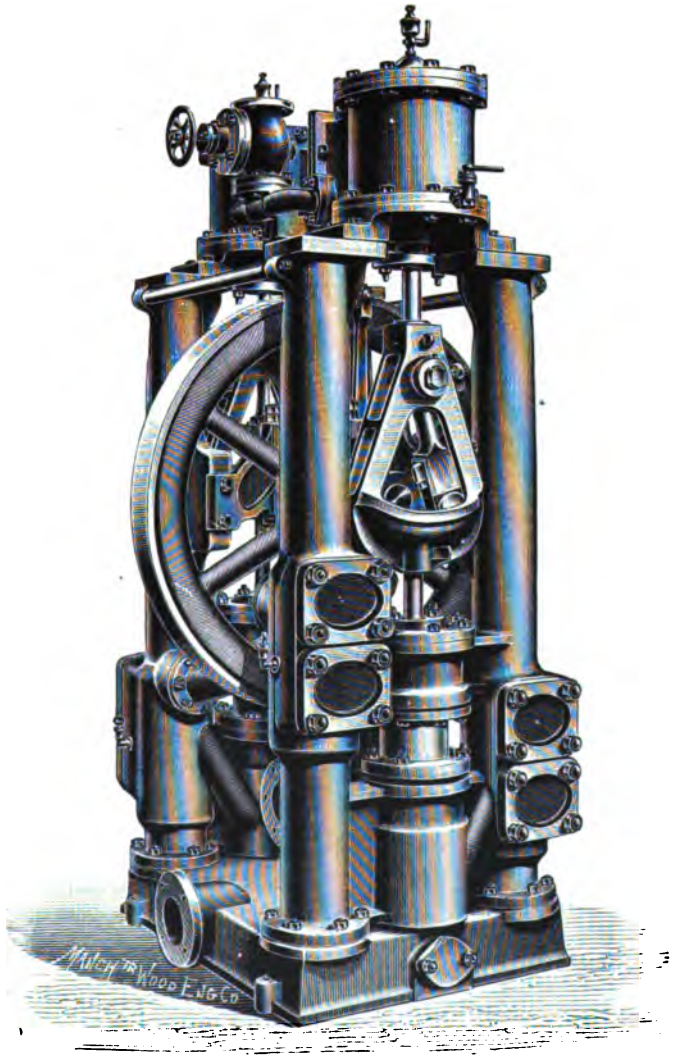


FIG. 168.—Pearn's Quadruple-Acting Ram-Pump.

rams half the water flows up the rising main and the other half goes into the auxiliary ram barrels, to be discharged on the up-stroke of same, thus giving four discharges in one revolution with only four valves instead of

eight, as is usual in quadruple pumps; consequently a very steady flow of water in the delivery pipe is maintained, which lessens the shock on pipes and joints, and makes the pump particularly suitable for very heavy pressures. The main rams and triangles are of cast-steel, the rams being cased with gun-metal; the auxiliary rams are also of gun-metal. All the rams are packed from the outside, and have ordinary stuffing-boxes and glands. These pumps will work very slowly if required, and will start at any part of the stroke, owing to the cranks being placed at right angles; hence they are specially adapted for working accumulators, for deep lifts in mines, etc.

Pearn's Quadruple-Acting Ram-Pump.

This engine (fig. 168) is a duplication of the single-ram double-acting engine, and with the same packing arangements.

The 'Simplex' pump, quadruple-acting type, of Mr. Elijah Ashworth, is an engine of similar construction, with the exception of the method of packing the ram, and therefore does not call for a description or illustration.

B.—COMPOUND STEAM-PUMPS

Compounding is rarely resorted to in engines of this class, the gain in economy of working for such comparatively small engines not being

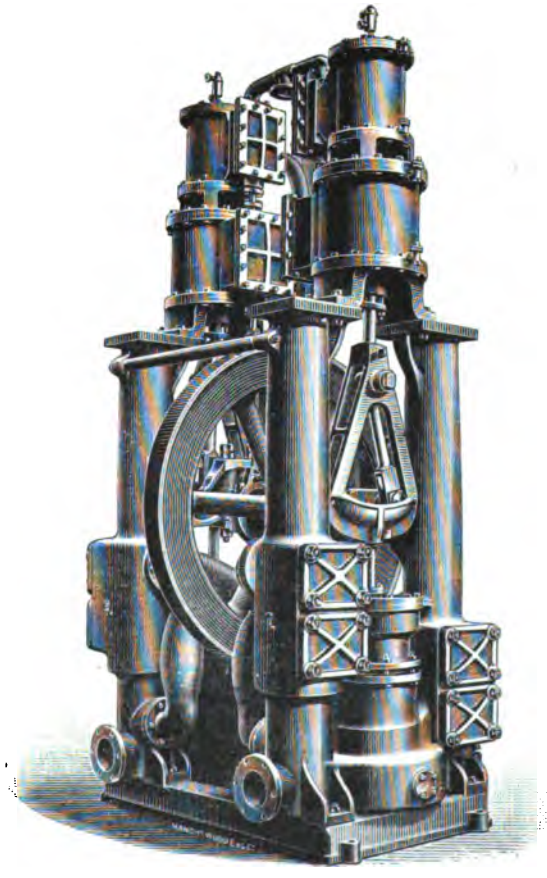


FIG. 169.—Pearn's Compound Quadruple-Acting Ram-Pump.

sufficient to compensate for the extra cost and complication and the additional 'head room' required. In their simple form they work expan-

sively, and the additional expansion obtained with a second cylinder is ordinarily not worth the while. The example given (fig. 169) has been designed principally for water-works and factories.

1. COMPOUND STEAM-CYLINDER, EXPANSIVE, CONDENSING ENGINES, WORKING RAM-PUMP.

2. TWIN COMPOUND STEAM-CYLINDER, EXPANSIVE, CONDENSING ENGINES, WORKING RAM-PUMPS.

Pearn's Compound Quadruple-Acting Ram-Pump.

This engine is depicted by fig. 169. The illustration does not show a condenser. Not being specially suitable for underground use, further reference is needless.

B.—NON-ROTARY VERTICAL ENGINES.

A.—SIMPLE STEAM-PUMPS.

The pumps of this class that have come under our notice are either of the piston or bucket type. For use underground as 'station' pumps and for general underground drainage they are not important: they may be conveniently used in wells, shafts, and other places where the floor space available will not admit of the use of horizontal engines, but only where the water is clean and free from grit.

Examples of the application of these pumps to sinking operations and the clearing of flooded shafts are given in the article on Sinking Pumps, page 280.

Many years ago there was a small number of examples of non-rotary vertical engines in the market, such as the 'Special,' 'Universal,' and 'Imperial' pumps, embodying the same principles of construction and action as the horizontal engines of the same names, but they did not give satisfaction, and one after another they were withdrawn. Their chief source of trouble was the steam-valve gear, the weight of the parts giving an unequal motion for the opening and closing of the ports. It was pointed out that this difficulty might be removed by either balancing the valve by a cataract or a weighted lever, or by twisting the steam-ports and placing the valve horizontally.[1] The latter expedient has been generally adopted, and in the principal pumps of this class the valve-chest is fixed horizontally, as will be seen on reference to the illustrations.

1. SINGLE STEAM-CYLINDER, NON-EXPANSIVE, NON-CONDENSING ENGINES, WORKING DOUBLE-ACTING PISTON PUMP.

THE 'SPECIAL' STEAM-PUMP.

This pump is made in a variety of sizes, from $3 \times 2 \times 9$ inches to $21 \times 14 \times 24$ inches, dealing with from 800 to nearly 40,000 gallons per hour under a head of 300 feet. It is also made in a type suitable for heads of 600 feet: the advertised sizes range from $14 \times 5 \times 24$ inches to $18 \times 6 \times 24$ inches, capable of raising from 5,000 to 7,200 gallons per hour. Any required size can of course be made.

[1] *Mine Drainage*, 1st ed. p. 222.

The dimensions of the 21 × 14 × 24-inch pump (300 feet series) are: height to the top of the air-vessel 15 feet, width and depth 5 × 6¼ feet approximately; the 18 × 6 × 24-inch pump (600 feet series): height to

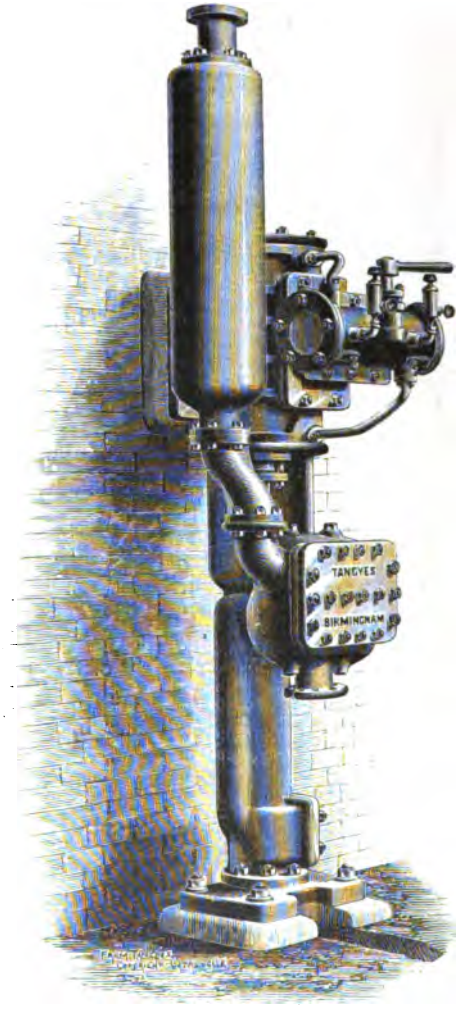


FIG. 170.—The 'Special' Steam-Pump (600 feet vertical series).

the top of the air-vessel 11 feet, width and depth 3¼ × 5¼ feet approximately.

Fig. 170 is an elevation of a 14 × 6 × 24-inch pump of the 600 feet series, and is known as a 'bucket' pump, *i.e.*, the piston is leather-packed, but it can also be supplied packed with rings in the usual way. The pumps of

this series are adapted for a maximum steam pressure of 100 lbs. per square inch.

Evans's 'Cornish' Steam-Pump.

This is also a bucket-type pump, and is shown at fig. 171, which is an elevation of the 18 × 8 × 24-inch size, suitable for heads up to 300

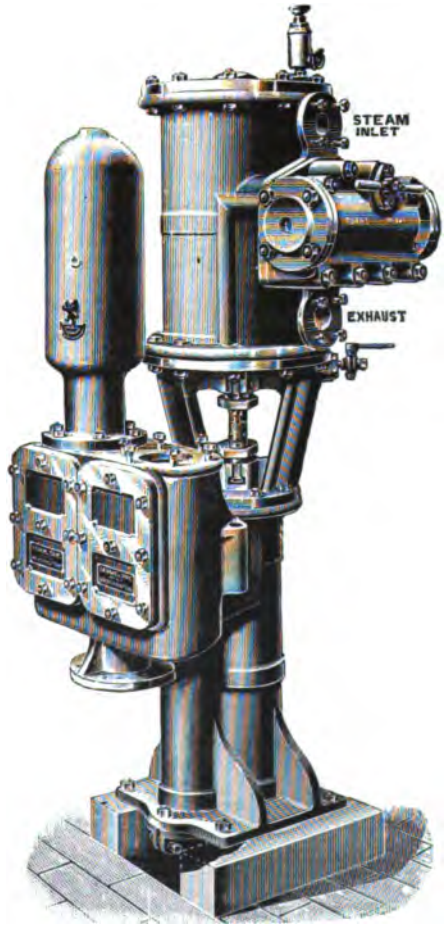
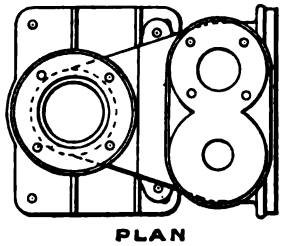


Fig. 171.—Evans's Vertical 'Cornish' Steam-Pump.

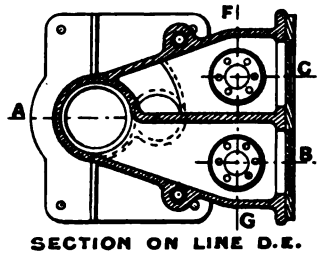
feet, and for steam-pressures to 100 lbs. per square inch. It is made in sizes ranging from 12 × 6 × 24 inches to 24 × 14 × 24 inches. The respective capacity of the sizes named is 7,340 and 39,980 gallons per hour at a speed of 100 feet per minute. Fig. 172 is a plan, and fig. 173 is a plan section of

the pump part, showing the ram-case, the valve-chamber, and valves; figs 174, 175, and 176 are sectional elevations which are self-explanatory.



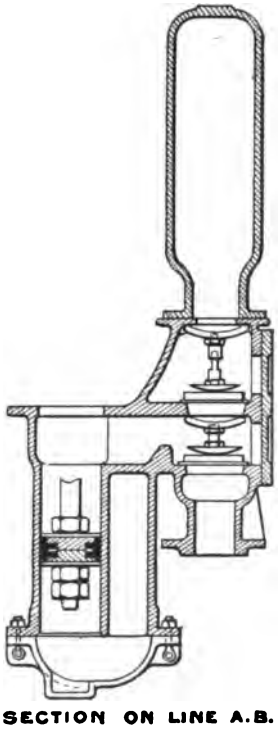
PLAN

FIG. 172.



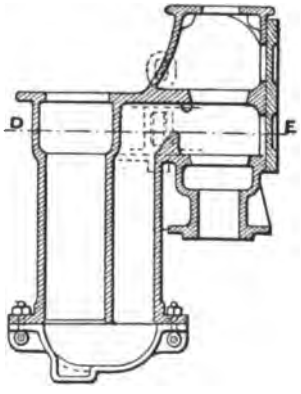
SECTION ON LINE D.E.

FIG. 173



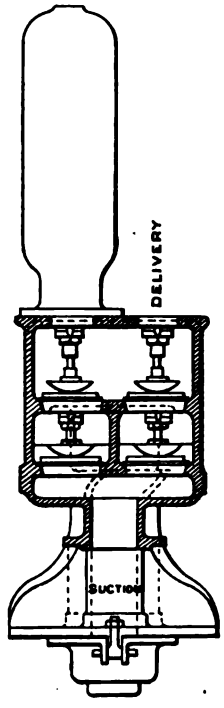
SECTION ON LINE A.B.

FIG. 174.



SECTION ON LINE A.C.

FIG. 175.



SECTION ON LINE F.G.

FIG. 176.

Evans's Vertical 'Cornish' Steam-Pump; Plan and Sections.

2. TWO STEAM-CYLINDER, NON-EXPANSIVE, NON-CONDENSING ENGINES, WORKING DOUBLE-ACTING PISTON PUMPS.

B.—COMPOUND STEAM-PUMPS.

1. COMPOUND STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES, WORKING DOUBLE-ACTING PISTON-PUMP.

2. TWIN COMPOUND STEAM-CYLINDER, EXPANSIVE, NON-CONDENSING ENGINES, WORKING DOUBLE-ACTING PISTON-PUMPS.

Bailey's Compound Duplex Steam-Pump.

Fig. 177 is an elevation of this engine, the makers of which have a horizontal arrangement thereof. It will be observed that the steam-valves are arranged vertically. It is advertised in sizes varying from 4 inches high-pressure and 7 inches low-pressure cylinders, 4-inch pump-cylinder and 6-inch stroke, to 12- and 20-inch high and low-pressure cylinders respectively, 12-inch pump-cylinders, and 12-inch stroke. Like the Simple Duplex class referred to, these pumps are more suitable for boiler-feeding, factories, and general purposes at surface, than for underground pumping, and may therefore be dismissed without further comment.

Fig. 177.—Bailey's Compound Duplex Steam-Pump

C.—SINKING-PUMPS.

Appliances known as sinking-pumps are available for a variety of operations in the exploitation of mines. The selection of the pump to be employed is governed by the precise nature of the work, such as the sinking of new shafts, the deepening of existing shafts, the pumping out of flooded workings, and the recovery of submerged mines.

It will assist us to a methodical treatment of the subject if we deal seriatim with these drainage operations, which may be epitomised as follows:—

I. The sinking of new shafts.

II. Sinking in a partially developed mine.

III. The recovery of flooded workings and 'drowned-out' mines.

I. *Appliances used in the sinking of new shafts.*—In the opening-up of a new mine or the sinking of a new shaft, the difficulty that confronts the mining engineer is to decide what the capacity of the pumping plant shall be, as the quantity of water that will be met with is such an uncertain factor. In the case of a new mine the manager or engineer will have to consider the geology of the district and the surface configuration. In this he would be helped by the experience gained in other mines similarly situated. In many instances in Cornwall the object in starting a new mine or sinking a new shaft is to intercept a lode or lodes in the adjoining 'sett.' It has often happened that a 'sett' has been acquired contiguous to a rich mine in the hope of intercepting some of its lodes; these are generally at a considerable depth, and as they have a certain well-defined underlie or dip, a close approximation can be formed of the depth at which they may be expected to be intercepted in the new venture. Thus some idea of the magnitude of the general operations can be formed and, guided by the practice of other mines in the neighbourhood, the scale of pumping machinery suitable thereto. Consideration would, of course, be given to the extent to which the adjoining mine would be likely to drain the new mine. It often occurs that where two mines are working in the same neighbourhood one of the twain gets most of the water owing to the peculiar disposition of the strata and the presence of a 'cross-course,' the more fortunate neighbour being a comparatively dry mine. In other instances the water is more equally distributed, and where this is so, the stoppage of the one mine so seriously affects the other, owing

to the water finding its way from the abandoned mine, that it has not infrequently been necessary to reinforce the pumping plant, or to keep the pumping engine of the abandoned mine at work. In other instances the miner has nothing to guide him but the general experience in mining in other parts of the county in similar strata. Cornish mines are generally heavily watered; in many instances they are unnecessarily wet because the agents do not attend to the surface-water, or because the lords permit the streamers to meddle with the adits. It is noteworthy that mines in the slate formation carry more water than those in the granite.

Another point to which serious attention is needed is the position of the shaft. Some idea must be formed before beginning to sink of not only the magnitude of the pumping operations that may have to be undertaken, but the position best calculated to drain and, if it is intended to wind through the same shaft, to work the ore ground.

The size of the shaft will depend upon its character. If an engine shaft simply, it need only be large enough to contain the pitwork (*i.e.*, pump-rods, main column, etc.), a ladder-road for examining and repairing the pitwork and for other purposes, and a sufficient gangway for lowering and raising the largest castings. If it is intended to wind through the same shaft, it must be made considerably larger.

'Although it is all important that ample room be provided for the requirements, yet it is obvious anything larger than that actually required would be a waste of money not only in excavating extra ground, which is very expensive in hard rock, but in laying out every detail, because the greater the diameter, so must all the girders, dividings, and cage road framing be proportionally increased in sectional area, and no doubt many shafts are sunk without due consideration as to the cost of these details.'[1]

We have not the space, neither is it our province, to discuss the laws which govern and the circumstances which affect the infiltration of rain-water through the soil and the underlying strata; the collection, the distribution, and the circulation of water in and through the rock beds and strata; the effects of springs, the influence of veins, cross-courses, faults, etc., nor the means to be adopted to lessen, as much as may be practicable, the percolation of surface water, and precautions underground to prevent the influx of water into the exploited points from contiguous workings. Our purpose is to consider the best means for ridding the miner of the water which, hydra-like, has poured into his workings from a hundred points.

The subjects that claim the most careful attention of the mine manager and engineer, and upon which the opinion of experienced authorities should be sought, may be briefly recapitulated as follows:—

I. The surface configuration of the district, with special reference to

[1] Nicholas Trestrail, Assoc. M.I.C.E.: *The Basset Shaft* (*vide* '*The Mining Journal*,' May 28, 1898).

outcroppings, permeable strata, and its general physical features as affecting its capacity to absorb rain and to allow its infiltration through it.

II. The average and the greatest rainfall of the district in the rainy seasons.

III. The geological character of the district, with particular reference to the dip and direction of lodes and cross-courses.

IV. Neighbouring mining operations, if any, and the quantity of water met with.

V. The probable or possible extent and depth of the operations about to be undertaken.

The prosecution of these inquiries will be attended with greater or less difficulty and more or less success, according as little or much is known experimentally of the geological character of the district. It is comparatively easy to form a rough estimate of the capacity of the pumping plant required for a mine in a familiar district, where there are neighbouring mines, and the accumulated experience of generations of miners may be requisitioned. When, however, the operations are in a district which has either not been previously exploited, or only to a small depth, the problem will be very difficult of solution. The miner can then only fall back upon what is or may be known of the geological and physical features of the district, and the experience acquired in mines in other districts in the same or similar geological formations.

There can be no doubt that a great quantity of the water pumped out of our mines is rain-water. Attention has not been sufficiently directed to its great absorption by the surface of the land, and consequently efforts are rarely made to minimise the evil by drawing off as much as possible of the surface water by means of drains, launders, etc., into some natural outlet, by puddling hollows, beds of streams, and broken ground. It often happens that former workers in pursuit of ore leave numerous shallow pits and other excavations in which rain-water collects. The surface may from other causes be indented with cavities into which summer showers and winter floods pour and find lodgment until they are absorbed, and, reappearing in the deeper parts of the mine, make extra work for the pumps. It is most important that the adits be kept clear and in good order, and that they are not letting down water into the lower levels.

Notwithstanding all the pains that may be taken to gauge the approximate quantity of water that may be met with, and the utmost precautions that may be adopted to meet all emergencies, the unexpected sometimes happens, as when a heavy feeder is struck, or a great natural reservoir is tapped, or the pent-up flood in old workings not suspected to be within harmful distance, bursts through the intervening barrier. Thus is the utmost attainable limit of human prevision sometimes baffled.

The subject thus far has been considered from a Cornish point of view, but the remarks are equally applicable to other metalliferous mining

districts. The same care, too, is needed in the coalfields, although the circumstances are not quite analogous.

The following methods are adopted when manual and horse labour, operating the crude appliances of tackle, windlass, and whim, have become unequal to the task of dealing with the water encountered when the shaft has struck the water-bearing strata, viz. :—

1. The Cornish system of lowering pumps (pipes) into the shaft, and forming a pump-column having a bucket operating in a 'working-barrel' or bucket-case, the whole being called a 'bucket-lift.' When a convenient length has been attained, varying from 15 to 20 fathoms, by the addition of extra pumps as the shaft progresses, the 'windbore,' which is the lowest part of the lift, is fixed into a cistern, and a new lift called the 'sinking lift' is formed, and supplies the other or 'drawing lift.' This, in turn, when a similar depth has been reached, is put into a cistern and another lift is formed. In this way there may be a succession of short bucket-lifts. When a considerable depth has been reached, say from 40 to 80 fathoms, the upper lifts are replaced by a 'plunger-lift' of, say, from 35 to 50 fathoms, which is a permanency, and a single bucket-lift, which for the time being is the sinking-lift. When a further considerable depth has been attained, a second plunger-lift is constructed, and so the work proceeds. It is the universal practice in Cornish mines to instal a permanent plant at the very outset.

2. Suspending steam-pumps in the shaft and lowering them as the sinking proceeds.

3. Hoisting the water in tanks.

4. The Kind and Chaudron system of boring and tubbing. The shaft is bored by Kind's apparatus, and the tubbing (cylindrical rings of cast-iron) lowered as the boring advances.

5. The Poetsch and the Gobert systems of freezing the rocks.

Systems 4 and 5 being only resorted to under extraordinary circumstances may be dismissed without further comment, and our observations confined to the first three systems, which are the only methods adopted under the ordinary conditions of mining. Of these the second system only comes within the scope of this work.

II. *Sinking in a partially developed mine.*

1. The Cornish system.
2. Steam-pumps placed underground: one pump in a 'station' some distance up the shaft, and a sinking-pump in or near the sump.

III. *The recovery of flooded workings and 'drowned-out' mines.*

1. The Cornish system.
2. Steam-pumps swung in the shaft and lowered as the water recedes. Pulsating steam-pumps of the Pulsometer class suspended and lowered in a similar manner.
3. Hoisting the water in tanks. This mode of drainage is not only

often resorted to for initial operations preliminary to the installation of a permanent pumping-plant, but in some mining regions is adopted in preference to any system of pumping for heavy drainage.

The following varieties of pumps are made, all of the non-rotary class, and usually of the single-cylinder type, viz. :

I. Horizontal Pumps.
- (*a*) Bucket.
- (*b*) Piston.

II. Vertical Pumps.
- (*a*) Bucket.
- (*b*) Piston.
- (*c*) Bucket-Plunger.
- (*d*) Plunger.

Duplex pumps do not appear to be so extensively employed, as they require more room in the shaft. In the United States large vertical pumps with compound cylinders arranged 'tandem' are in use in some mines, particularly on the Pacific Coast. The Palmer Sinker (figs. 185 and 186) is a double-cylindered pump; the two cylinders, alike in size and action, are placed 'tandem,' and their pistons are directly connected to the rod actuating the pump-plunger. The advantage of this arrangement lies in the fact that it takes up less space in the shaft than one large cylinder. Nothing is claimed for it in the economical use of steam.

The horizontal sinking-pumps having been noticed in a previous page, it only remains for us to consider the second and more important group, the vertical pumps.

Sizes, Weights, and Speed.

A Palmer Sinker (fig. 185), 16 × 12 × 20 inches, for a maximum water pressure of 125 lbs., has the following dimensions—14 feet 7¼ inches, by 3 feet 4⅝ inches, by 3 feet 2½ inches. Its weight is 4 tons 11 cwts. 8 lbs., and its capacity 9·8 gallons per stroke and 35,220 gallons per hour at 100 feet piston speed per minute. The steam and exhaust-pipes are 3 inches and 5 inches respectively, the suction-pipes 8 or 10 inches, and the discharge-pipes 6, 7, or 8 inches. The pump to withstand 200 lbs. maximum pressure (fig. 186) is slightly larger, the dimensions being 14 feet 8¼ inches, by 3 feet 10 inches, by 3 feet 3 inches. The weight is 6 tons 1 cwt. 1 qr. 20 lbs. The following are some of the sizes in which the 'Denaby' Sinking Pump (fig. 187) is made :—

Dia. of steam cylinder	Dia. of large ram	Length of stroke	Approx. water per hour	Dia. of suction pipe	Dia. of delivery pipe	Dimensions	Approx. weight
in.	in.	in.	gallons	in.	in.	ft. in. ft. in.	tons cwts.
12	8	16	4,800	6	4	2 4 × 2 0	1 8
15	10½	18	8,600	8	5	2 10 × 2 4	2 ½
22	14	30	15,500	10	7	4 6 × 2 8	3 18
30	18	36	26,000	14	9	5 0 × 3 8	6 3

The following are a few of the smaller and the larger sizes of the Knowles Bucket-Plunger Sinking-Pump (fig. 184):—

Dia. of steam cyl.	Dia. of lower plunger	Dia. of upper plunger	Lgth. of stroke	Water per hour	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dia. of exhaust pipe	Dimensions	Weight		
in.	in.	in.	in.	gallons	in.	in.	in.	in.	in.	cwts.	qr.	lb.
6	5⅜	3¾	7	3,480	3½	2	¾	1	54 × 22 × 17	6	1	0
8	5⅜	3¾	10	3,480	3½	2	1	1¼	65 × 25 × 14	8	1	11
10	7	5	10	6,120	4	3	1¼	1½	74 × 26 × 19	10	1	2
18	12	8½	16	17,700	8	6	2	2½	123 × 39 × 34	46	3	14
20	14½	10	24	24,480	10	6	3½	4	150 × 41 × 39	66	1	10
24	14½	10	24	24,480	10	6	3½	4	156 × 45 × 38	71	0	8

The Palmer Sinker, which was used in the flooded Argentum-Juniata mine for a nearly continuous run of three months, was lowered and operated through a shaft opening of 4 feet by 5 feet in the clear, and was not backed up a foot during the entire time.

For continuous work of such a rough character a moderate speed, say, 100 feet per minute, should suffice. In an emergency the pump can be run at a much higher speed.

Capabilities.

The following information supplied by the Blake and Knowles Pump Co., of work done by a Palmer Sinking Pump, shows what can be accomplished by pumps of this class in an emergency:

'In the month of August 1894, one of these pumps was set to work at the Argentum-Juniata Mine at Aspen, Colorado (which had been flooded for two years previous), after a severe preliminary test at the Mollie Gibson Mine, during which it was run at a delivery of from 610 to 1,730 gallons per minute, under a varying head of from 150 to 425 feet vertical lift, with a steam pressure of 85 lbs. at the pump.[1]

'During a practically continuous run of ninety days it lowered the water in the Argentum-Juniata mine a vertical distance of 709 feet, the actual time consumed in beating down the water being thirty and a half days, while for the balance of the time it was holding the water during the placing of a new Knowles Compound Condensing Duplex Pumping Engine at the 400-feet level, and the cleaning and starting of the two Knowles pumps at the 600- and 900-feet levels respectively, which had been under water continuously for more than two years. During this service the Palmer Sinker was lowered and operated through a shaft opening of 4 feet by 5 feet in the clear, was not backed up a foot during the entire time, and worked at an average delivery of from 700 to 900 gallons

[1] Mr. Palmer, of Aspen, Colorado, by whom the pump which bears his name was designed, first tested its merits at the Mollie Gibson Mine, of which he is the manager. —S. M.

per minute, sometimes being pushed to 1,000 or 1,100 gallons for several consecutive days.

'In September 1895, a Palmer Special Sinker was started in the Gregory Incline at Black Hawk, Colorado, and in fifteen days' continuous pumping lowered the water a vertical distance of 105 feet, lifting at an average about 800 gallons per minute through a 6-inch column, and at times more than 1,000 gallons. Remarkable results were accomplished in the course of this work, in the face of considerable difficulty in making sufficient steam, owing to old and defective boilers.'

The 'Denaby' Sinking Pump has done excellent work in connection with the Denaby Main Sinking at Cadeby, where two shafts were being sunk into the Barnsley seam, a depth of about 600 yards. When in January 1890 one shaft had reached a depth of 40 yards and the other 30 yards, operations were seriously retarded by the great quantity of water met with. A 'Denaby' pump, then used for the first time and specially made for the purpose, with a capacity of 50,000 gallons per hour against a head of 100 yards, was suspended in one of the shafts. Additional pumps of slightly larger capacity were afterwards installed. Writing under date February 12, 1892, the Denaby Main Colliery Company, Ltd. (Mexbro', near Rotherham), say—'We have much pleasure in stating that we have had eight 'Denaby' Pumps at our Cadeby sinkings, and we are well satisfied with their performance. The water was lifted 120 yards in two lifts, and approached at times nearly 300,000 gallons per hour.'

Mode of Operation.

The pump may be slung in the shaft by chains or wire-rope hanging by the tackle, or, if it be a large pump, from the hoist drum, or it may be hooked to the timbering by heavy iron claws which are provided for this purpose.

As the sinking proceeds extra lengths of pipe are added at the top of the shaft. A telescopic suction-pipe enables the sinking to proceed several feet, generally 9, without necessitating the lowering of the pump. A similar method of extending the steam-pipe is adopted in what is perhaps one of the largest colliery sinkings of modern times—two large shafts of over 600 feet deep by the Denaby Main Colliery Co. at Cadeby, near Doncaster—four sinking-pumps of the Denaby type were slung in each shaft, each pump having its own separate winding drum and steel wire-rope, enabling each or all of the pumps to be raised or lowered at will.

In the case of large pumps it will be found advantageous for them to work between guides to secure proper alignment with the steam-pipes and rising-main. When required to work in inclined shafts, dips, etc., a tramway or rail is laid down for the pump, the latter being mounted on a wooden trolley with flange wheels.

The characteristics of the American mining engineer are nowhere, perhaps, more strikingly presented than in initial operations of this kind.

To his English confrère, with his greater deliberation and care and higher regard for economy of power and material, he goes ahead with an impulsiveness and a haste that sometimes border on the reckless and the audacious. With the Americans 'time is money' verily, and for the sake of mere speed they will make sacrifices that would not be tolerated in this country. With us economy, a general all-round conservation of capital, is the prime essential, except of course in great emergencies where time is the dominant factor. With the Americans speed is the supreme desideratum. This may be seen in the way they set about operations of this kind. Once resolved upon their objective, they 'hurry up' all round, and have the needed plant on the spot and working in a surprisingly short time. There is no doubt that for work of this kind their experience is unequalled. They have incomparably wider mining areas for exploitation than are to be found in any other country, and as the steam-pump is their favourite agent, the greatest exploits with the type of engine under consideration are performed by American engineers and miners.

They will run a pump for what it is worth, and when it breaks down drop another. Having to deal with water carrying grit this occurs rather frequently, necessitating a pump in reserve, which can be dropped immediately the other gives out. For this reason plunger-pumps are preferable for sinking. Of course, the lower the suction-nozzle is advanced towards the broken ground and the débris, the greater the quantity of sand and grit that will be drawn into the pump. The nozzle, therefore, should be kept as near the surface of the water as possible in actual sinking operations. In pumping out flooded shafts the water is naturally cleaner, and not until the nozzle gets near the bottom does the suction draw up sand, grit, etc. The great mischief wrought by the latter has led to the adoption, in some instances, of a settling chamber attached to the pump, with a door for removal of the accumulated sand, etc. For convenience of handling, and to draw up out of the way during blasting, the lower part of the suction-pipe consists of hose or other flexible material.

Cost.

The tables on the next page give the prices of the Evans 'Griff' Pattern and 'Straight-line' Pattern respectively. The two series of prices of the 'Straight-line' Pump are for pumps suitable for heads of 300 and 600 feet respectively.

The following are specifications and prices of 'Denaby' Sinking-Pump plant for a Mexican and Chinese mine respectively. Each plant consists of a 'Denaby' Sinking Pump with all fittings; one steel portable or vertical boiler with mountings and injector, steam, exhaust, and delivery-pipes for 300 feet lift, telescopic suction-pipe, clips for pipes and for wire-ropes:

	Mexico	China
Price, complete to specification	£400	£560
Capacity in gallons per hour (approx.) . . .	4,800	8,600
Weight of boiler (approx.)	40 cwts.	70 cwts.
Weight of pump and pipes, not including boiler (approx.)	4 tons	6 tons

The plant is made specially suitable for export; the pump, being built up of small parts, can readily be carried overland.

FIG. 179.

Diameter of steam cylinder	Diameter of pump	Length of stroke	Approximate weight	Dimensions	Price
in.	in.	in.	cwts.	in.	£
16	8	24	31½	38 × 37 × 93	106
18	9	24	41¾	44 × 41 × 98	145
18	12	24	57	47 × 50 × 117	175
20	10	24	51	46 × 44 × 103	169
20	16	24	89½	56 × 63 × 133	251
21	11	24	60¼	50 × 49 × 105	190
21	16	24	93½	59 × 65 × 133	262
22	11	24	64¾	50 × 49 × 106	204
24	12	24	74¾	51 × 52 × 117	240
24	16	24	102½	62 × 66 × 133	302

FIG. 180.

Diameter of steam cylinder	Diameter of pump	Length of stroke	Approximate weight	Dimensions	Price
in.	in.	in.	cwts.	in.	£
16	8	24	56	41 × 38 × 163	190
18	9	24	73	47 × 44 × 169	241
18	12	24	102	54 × 46 × 176	298
20	10	24	92	50 × 47 × 175	275
20	12	24	107	54 × 47 × 178	315
21	10	24	95	51 × 49 × 175	288
21	12	24	110	55 × 50 × 178	328
22	12	24	115	55 × 50 × 179	344
24	12	24	120	57 × 53 × 181	376
20	10	24	107	54 × 47 × 175	324
22	12	24	135	61 × 50 × 180	407
24	12	24	140	63 × 53 × 182	439
26	9	24	111	56 × 58 × 177	388
28	10	24	130	59 × 60 × 181	446
30	12	24	155	67 × 63 × 185	542
32	12	24	160	67 × 65 × 186	583
34	12	24	166	69 × 70 × 187	631

The 'Special' Sinking-Pump.

Fig. 178 is an elevation of this pump, 14 × 6 × 24 in. size, which is fitted with Floyd's exhaust steam-condenser. The pump-piston is leather-packed.

Fig. 178.—The 'Special' Sinking-Pump.

It will be observed that the steam-chest is disposed horizontally. The general arrangement and the method of slinging in the shaft are sufficiently

evidenced by the illustration. Messrs. Tangyes, Limited, Cornwall Works, Birmingham, are the makers.

Evans's 'Cornish' Sinking-Pump.

The 'Griff' Pattern.

This pump is made in two distinct types—the 'Griff' pattern and the 'Straight Line' pattern, of which figs. 179 and 180 are illustrations. The first is a bucket arrangement, suitable for heads up to 300 feet, and the

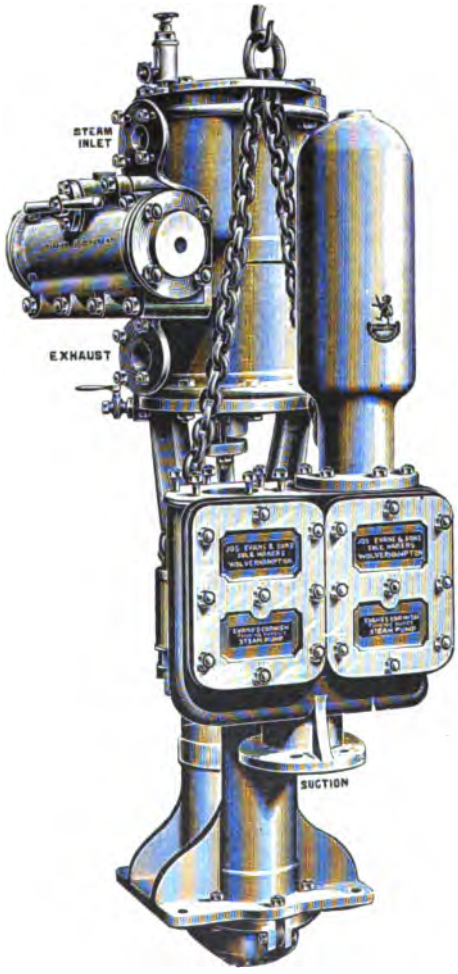


Fig. 179.—Evans's 'Cornish' Sinking-Pump (the 'Griff' pattern).

Fig. 180.—Evans's 'Cornish' Sinking-Pump (the 'Straight Line' pattern).

steam-cylinder for steam-pressures up to 100 lbs. per square inch. It is, when required, made with an easily removable liner where gritty water has to be handled. The arrangement of steam-chest is similar to that of the 'Special' Pump. The illustration represents the $14 \times 8 \times 24$ in. size.

Evans's 'Cornish' Sinking-Pump.

The 'Straight Line' Pattern.

In this pattern the pump is double-acting of the outside-packed ram type, fitted with Evans's improved Differential Ram. It is made in types suitable for 300 and 600 feet heads respectively, with steam-pressures up to 100 lbs. per square inch. The elevation (fig. 181) shows the pump parts in section, and makes clear the differential action of the ram. This pump is admirably adapted for pumping gritty, sandy, or muddy water, as the ram is externally packed, and there are no internal leathers or packings as in the case of piston and bucket-pumps, requiring frequent renewal. The pump-valves are easy of access through the doorways, and all parts can be readily examined, and the ram, piston, or piston-rod can be withdrawn without disconnecting any pipes. Evans's patent rotative disc valves are used.

The makers are Messrs. Jos. Evans & Sons, Culwell Works, Wolverhampton.

The 'Northey' Sinking-Pump.

This pump, shown at fig. 182, with the pump part in section, has an internally packed double-acting ram, to get at which the ram-case must be disconnected. The advertised sizes range from $7 \times 3\frac{1}{2} \times 12$ in. to $18 \times 9 \times 16$ in., with a capacity per stroke of ·5 to 4·4 gallons respectively. The pump arrangement appears to be precisely similar to that of the 'Cameron' Sinking Pump, another well-known Transatlantic engine. The makers are the Northey Manufacturing Company, Toronto, Canada.

The 'Blake' Bucket-Plunger Sinking-Pump.

This pump, represented at fig. 183, has a bucket and plunger arrangement similar to that of the 'Knowles' Pump by the same makers (fig. 184), and as this pump is described with some detail the reader is referred thereto.

The 'Knowles' Bucket-Plunger Sinking-Pump.

The salient feature of this pump is a combined bucket-plunger. A solid plunger is bolted to a hollow and larger plunger which carries a bucket midway between its two ends, as shown at fig. 184, the bucket forming the seat of the discharge-valve. The action is as follows: at the up-stroke the water enters through the suction-valve, and follows the ascending plungers and bucket, and fills the space between the two valves.

The stroke being completed, the suction-valve closes as the plungers begin to descend, and the imprisoned water, having no other outlet, escapes through the bucket or delivery-valve, filling the space round the upper plunger and the discharge-chamber, and at the next stroke is carried into the rising main.

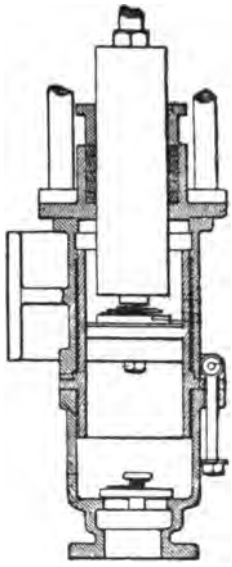


FIG. 184.

The lower plunger works in a removable cylinder of gun-metal composition, which can be readily replaced with little trouble and expense by a new one when worn out. The valves are of vulcanised rubber, and work on seats of gun-metal composition. Swing bolts admit of easy access to the valves and pump-barrel. Each pump is fitted with a ring bolt in the upper steam-cylinder head, to which tackle for raising or lowering can be readily attached. Adjustable wrought-iron 'dogs,' for hanging the pump to the shaft timbering, are bolted to the cylinders.

Pumps of this type are better adapted for raising clean water, such as in 'drowned-out' operations, where the solid impurities have settled to the bottom, than in actual sinking operations.

THE 'PALMER SPECIAL' SINKING-PUMP.

This pump has been designed to secure the greatest possible pumping capacity in a minimum space, and is especially adapted to the recovery of flooded mines and general excavating work requiring the most compact form of pumping apparatus. The arrangement of steam-cylinders adopted in this style of pump secures twice the capacity, theoretically, of one of the ordinary type occupying the same shaft space, and as there is practically no increase in the number of moving parts or amount of internal friction, more than double the ordinary capacity is claimed for it in actual service.

In this pump there are two steam-cylinders, precisely alike in size and action, placed 'tandem,' their pistons being directly connected to the rod actuating the water-plunger.

In the sizes shown, figs. 185 and 186, the steam-cylinders are each 16 inches, and the double-acting plunger 12 inches in diameter, giving a capacity of 587 gallons per minute at 100 feet of piston travel. The common stroke of steam-cylinders and plunger is 20 inches, and the speed of piston travel can easily run up to 200 or 210 feet per minute in case of emergency, corresponding to a delivery of 1,175 to 1,230 gallons per minute. The makers, Messrs. Blake & Knowles Steam Pump Co., Ltd., claim that this

PLATE XIV.

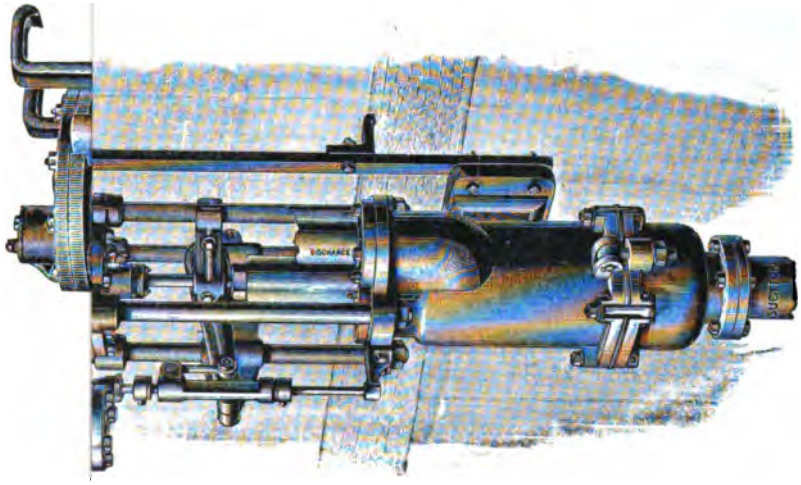
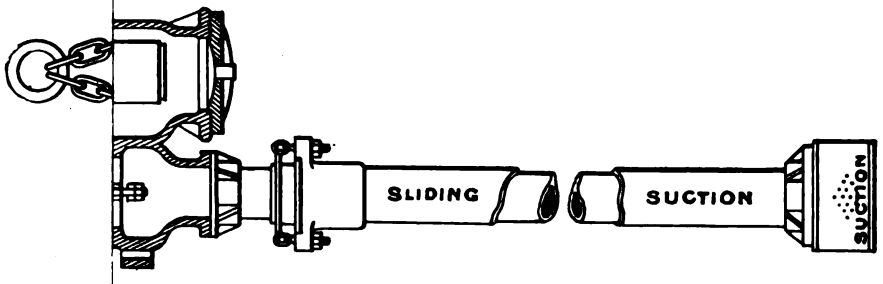


FIG. 183.—The 'Blake' Sinking-Pump.



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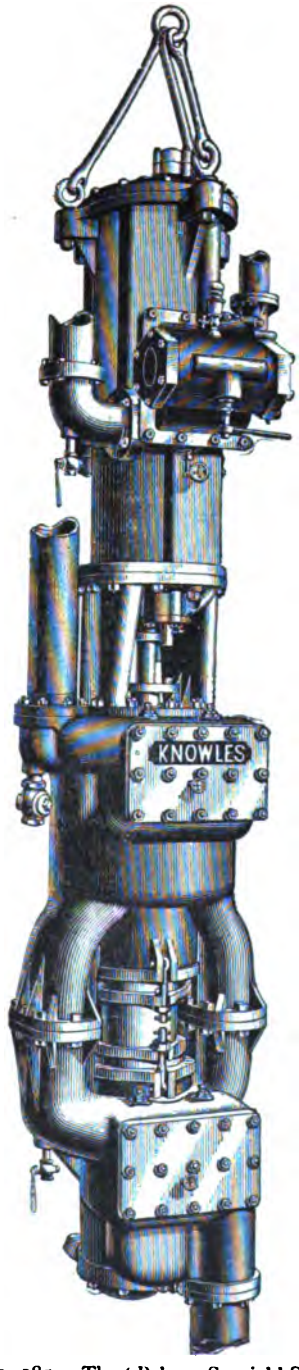


FIG. 185.—The 'Palmer Special' Sinking-Pump (low lift pattern).

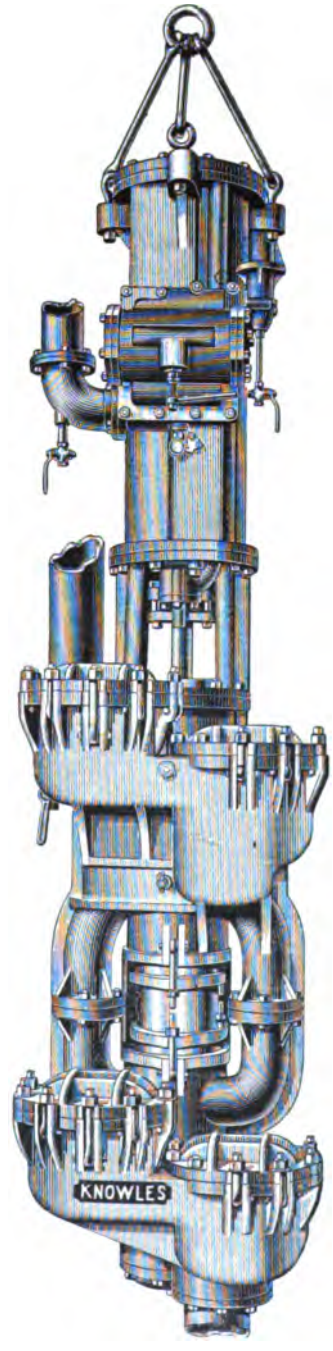


FIG. 186.—The 'Palmer Special' Sinking-Pump (high lift pattern).

is a capacity of more than three times that of any other type of pump which can be passed, endwise, through the same opening.

Extra heavy 'pot' valves of the latest improved design are used on the water-end of the high-pressure pattern, with free-swinging cover-bolts, allowing quick and easy access whenever necessary. The valves themselves are of the best vulcanised rubber, working on seats of gun-metal composition. Every detail is designed to secure especial strength to withstand the hardest usage, combined with the utmost compactness.

Fig. 185 is the pattern for lifts of 250 feet and under, fig. 186 for 250 to 400 feet.

The 'Denaby' Sinking-Pump.

Fig. 187 is an elevation of the small-size type of this pump, and fig. 188 is a section showing the pumping arrangement. It owes its name to the colliery where it was first used and with such conspicuous success. The following description is extracted from an account which appeared in the 'Manchester Guardian' of January 27, 1890, of a visit of the members of the Federated Institution of Mining Engineers to the Denaby Main Colliery, Cadeby, Yorkshire :—

'The pump consists of three hollow plungers; the upper pair are stationary, and over them slide barrels, which are connected to the steam-piston. From the lower end of these barrels projects the bottom plunger. This plunger works into the third barrel together with the two stationary plungers, and is secured by means of connecting-rods to the steam-cylinder. Thus there are two smaller barrels in connection with the large ram moving between the large barrel connected with the smaller rams. There is a system of valves in the junction between the smaller barrels and the large ram, constituting the delivery-valves; and another system of valves at the bottom of the large barrel, which constitute the suction-valves. The action of the pump is as follows :—As the bottom plunger rises, the water follows it into the lower barrel; at the same time, the water in the upper hollow plungers is forced into the rising main. On the down stroke the water in the lower barrel is forced through the lower plunger and valve into the upper barrels and plungers, and thence into the rising main. Thus there is a continuous delivery on the up and down-stroke. One of the upper plungers is open on the top, and forms the discharger orifice for the water, and the other is closed, so forming an air-vessel.

'The steam-cylinder is of the "Davidson" type.

'The patentees are Bailey and Lindemann, and the makers are Messrs. W. H. Bailey & Co., Salford, Manchester.'

With the exception of the Palmer pump, which has two cylinders arranged 'tandem,' the pumps thus far considered are of the single-cylinder class. We will now notice briefly those of the duplex class, giving as good examples the pump of Messrs. Frank Pearn & Co., Ltd., and the 'Gordon' pump, both of the outside-packed ram type. There are many other

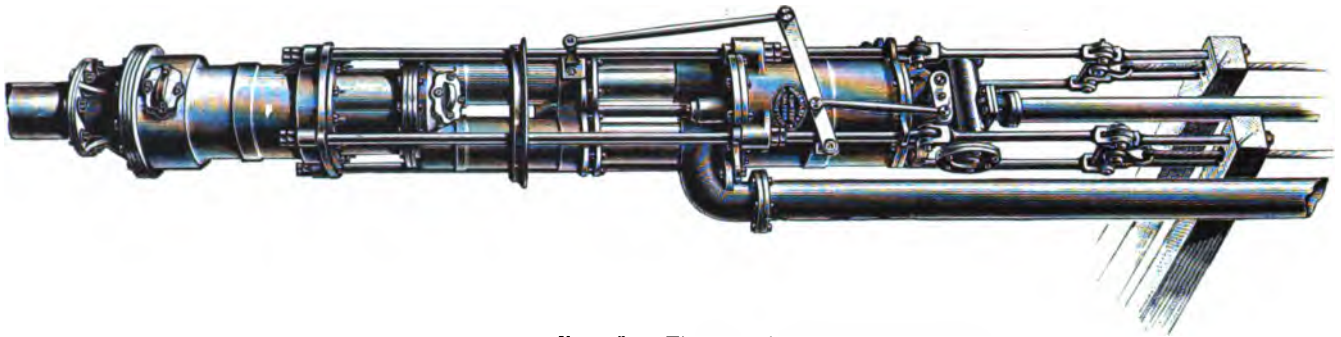


FIG. 187.—The 'Denaby Sinking-Pump.

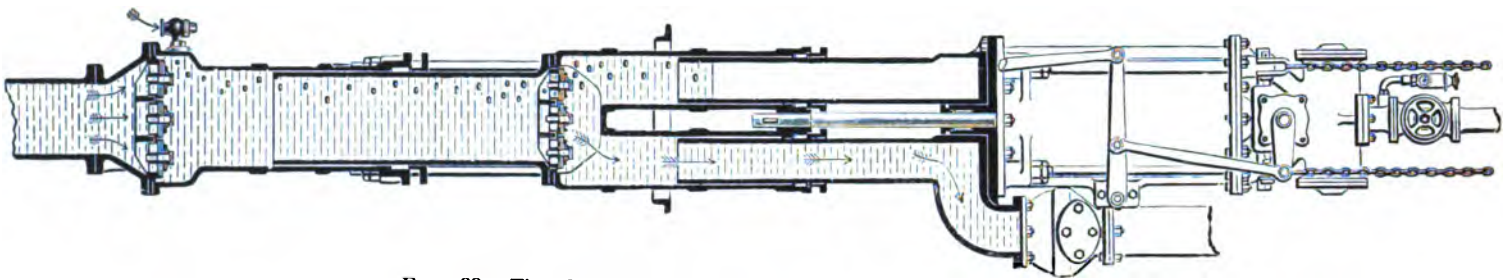


FIG. 188.—The 'Denaby' Sinking-Pump; longitudinal section of water-end.

admirable pumps of this class, such as the 'Worthington,' which occupies a distinguished position.

Pearn's Duplex Sinking-Pump.

This is a pump of the duplex ram type, of which figs. 189 and 190 are illustrations, and is made for very rough and heavy work. It has in common with all duplex pumps a continuous delivery, and, therefore, the vibration in the delivery-pipes and on the chains, which often takes place in single-cylinder pumps, is minimised. The pump-rams are outside-packed, and the direction of the water is practically in a straight line through the pump barrels, and is so arranged that the velocity of the water through the delivery-valves will carry sand and gravel forward without interfering with the action of the pumps. As in other duplex engines each pump has a separate cylinder, with valve gear worked from the opposite engine, and is arranged to give a pause at the end of each stroke. All the valves are easy of access, and are of a very durable type.

From the sectional illustration, fig. 190, it will be seen that the pump is of the differential type, single-acting on the suction, and double-acting on the delivery side. A is the main pump ram; B is the packing gland for the ram and C the packing. D is the fixed ram, which is one half the area of the main ram A. E is the main casting, which supports both the pumps and carries the steam-cylinders. F is a delivery passage which is common to both pumps, and G the crosshead, which is cast along with ram A, and is connected to the piston K by the two pump-rods J. The suction-valve is marked H, and the delivery-valve I.

The action is as follows:—When the ram A moves in an upward direction it opens the valve H, and fills the chamber between the suction and delivery-valves H and I. Upon the down-stroke the ram A discharges half its area forward to the delivery-pipe, the other half being taken up by the space left behind, which is equal to the fixed ram D, being one half the area of the ram A. Upon the up-stroke the remaining half is delivered forward through the delivery-pipe.

Messrs. Frank Pearn & Co., Ltd., West Gorton, Manchester, are the makers of this pump.

The 'Gordon' Duplex Sinking-Pump.

Fig. 191, which is an elevation of this pump, sufficiently indicates its special features and general construction. It will be observed that it is a well-designed pump, compactly made, and every facility is provided for reaching the valves and other wearing parts. Messrs. Hayward-Tyler & Co., London, are the manufacturers.

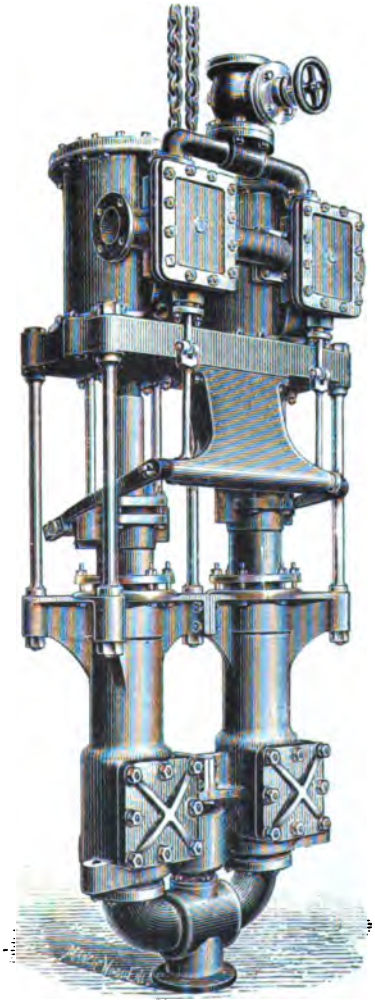


FIG. 189.—Pearn's Duplex Sinking-Pump.

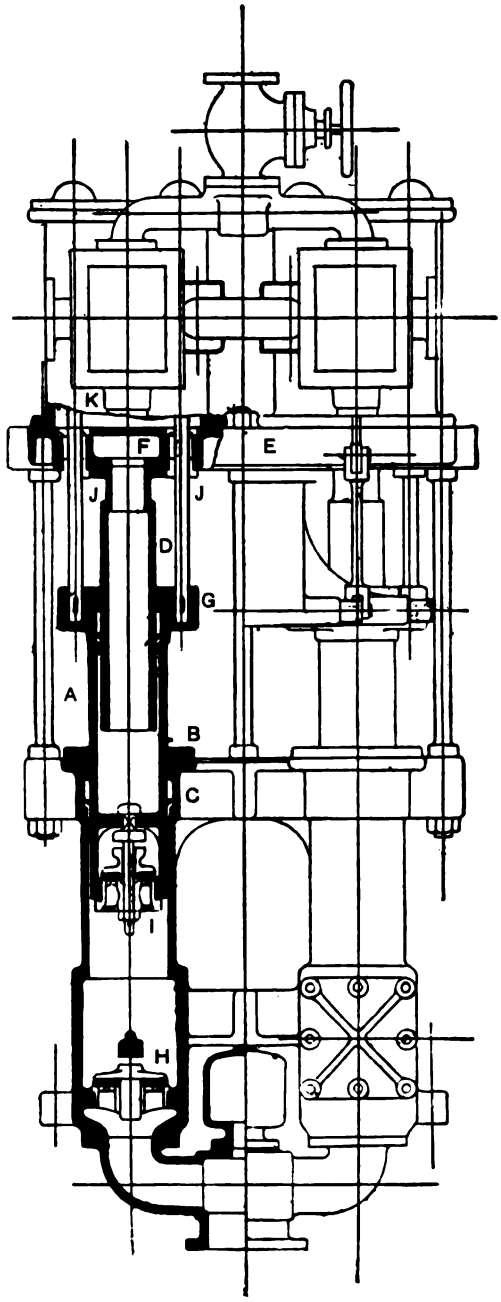


FIG. 190.—Pearn's Duplex Sinking-Pump; longitudinal section of the water-end.

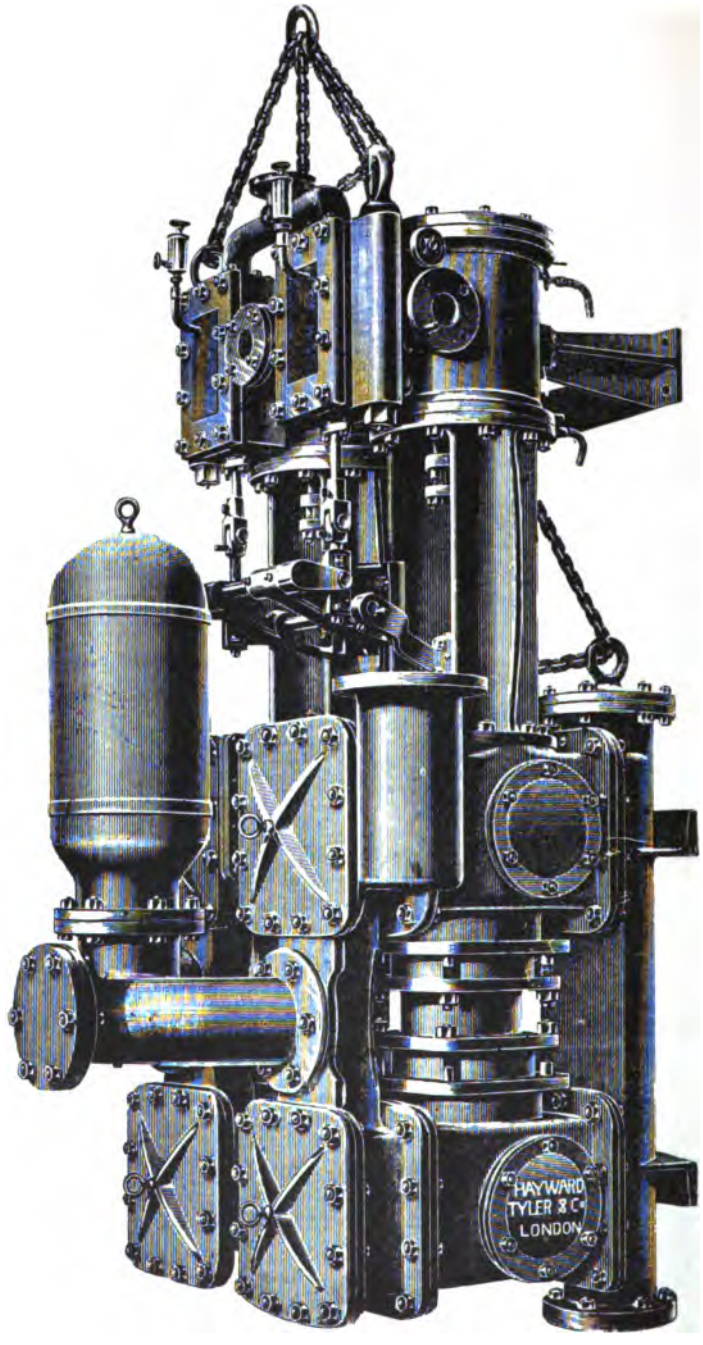


FIG. 191.—The 'Gordon' Duplex Sinking-Pump.

The 'Tipton' Sinking-Pump.

Fig. 192 shows this pump (which has compound steam-cylinders arranged 'tandem,' and is of the differential ram and bucket type), and the method of its application in the shaft. Fig. 193 is a side view. It may be slung on girders or round bars of a uniform length to match the same lengths of steam, exhaust, and water-pipes. It may be slung on one or two screws; the illustration shows it on one screw ready for lowering, which

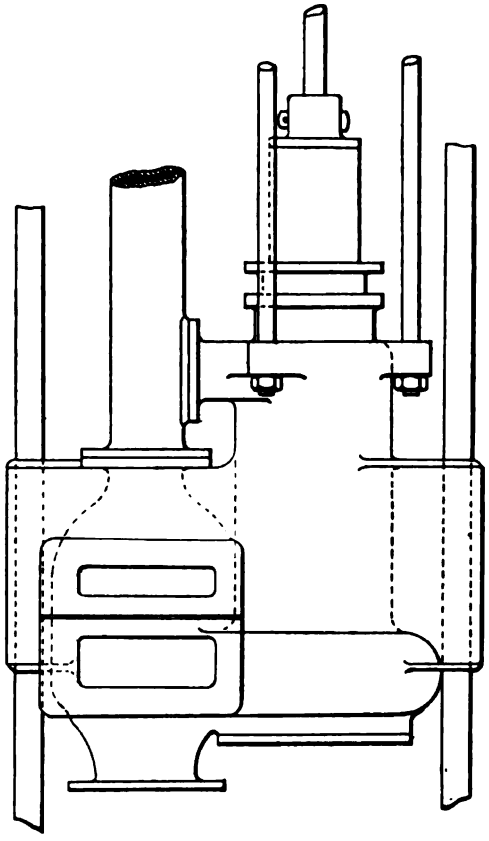


Fig. 194.—The 'Tipton' Sinking-Pump; elevation of water-end.

operation may be performed with a ratchet wheel or by a worm wheel, actuated by hand or power. The question of lowering tackle will, of course, be determined by the capacity of the plant and the depth of the shaft. The weight of the steam and exhaust-pipes is taken up on a provision made on the cylinder-cover, and the water-pipes are carried in a direct vertical line on the pump, all clamped together in a vertical position, at suitable intervals, to the carrying girders or iron bars. Figs. 194 and 195

show the pump in elevation and section. It will be noticed that only two valves are used, one for suction and one for delivery. On the up-stroke water follows the bucket through the lower or suction-valve and through the annular rows of holes in the liner, and on the down-stroke the same water is delivered through the upper or delivery-valve, half of it into the upper chamber due to the displacement of the ram, and the other half to the surface ; consequently on the next up-stroke of the bucket the remaining half is delivered to the surface and a fresh supply taken through the suction-valve, and so on. The special function of the liner in the working

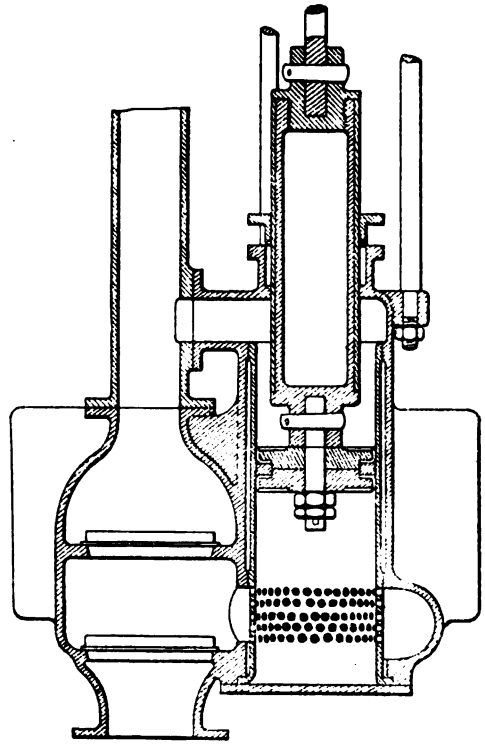
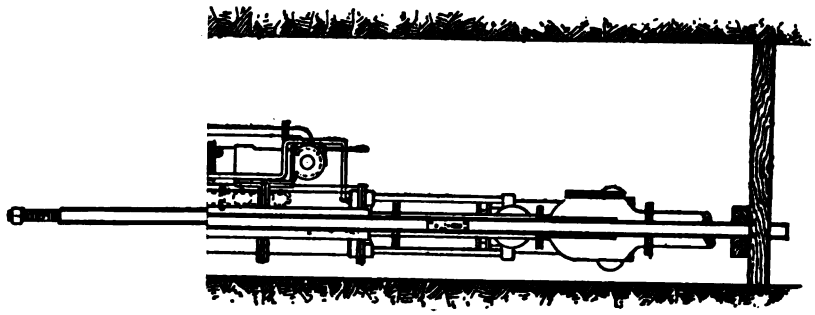
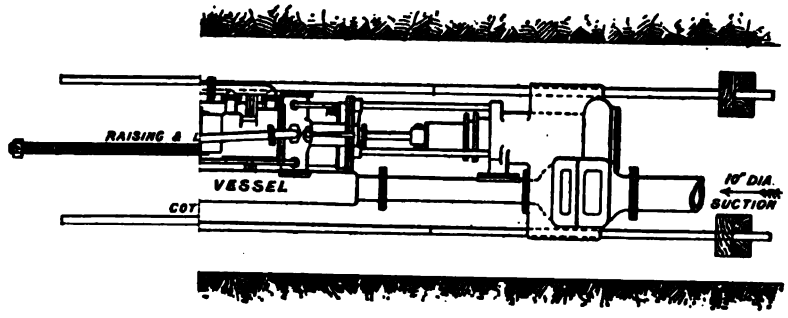


FIG. 195.—The 'Tipton' Sinking Pump ; sectional elevation of water-end.

barrel is to allow the bucket to be changed without damaging the cup leathers, and the upper annular row of holes admits any accumulation of air, which may be collected under the bucket, to be discharged on the completion of each down-stroke, when the bucket descends beyond the top row of holes, which it does without damaging the cup leather. The steam-cylinder has the same self-draining facilities as the ordinary horizontal type, the valve-gear being operated in exactly the same way without the aid of tappets, levers, or any extraneous gear, the whole forming a very neat and compact arrangement.

PLATE XV.





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D.—PULSATING STEAM-PUMPS.

The principle of raising water by the direct action of steam upon its surface is just exactly two centuries old, originating in the rather crude appliance invented by Thomas Savery in the year 1698, and described by him in his book, 'The Miners' Friend.' Captain Savery used this form of pump for draining mines in Cornwall before either Newcomin's atmospheric engine or Watt's 'Cornish' engine was in use. It was abandoned owing to its enormous consumption of steam. The idea has been revived and improved in the 'Pulsometer,' the best-known of this class of pistonless pumps, which had its origin, like so many of the pumps already noticed, in the United States, where it was invented by Mr. C. H. Hall, and was patented September 24, 1872.

As we shall presently see, the principle of its action is the direct application of steam to the surface of the water, upon which, in the first instance, it exerts a propulsive force, driving it from the one chamber of the appliance into the other, and then by its immediate condensation as it blows through the orifice leading to the delivery, and comes into intimate contact with the water in the delivery-pipes, a vacuum is rapidly formed in the just emptied chamber (the further admission of steam being cut off by closure of the steam orifice), into which the water rushes in a way analogous to the suction-end of an ordinary pump.

The pulsating steam-pump is of too limited a range of lift to be of general utility in mines, and is too expensive in the consumption of steam to be recommended for any permanent work. The most useful spheres of its application are quarries and other open workings, shallow pits and wells, docks, and general contractors' work, where the lift is very low, say from 20 to 30 feet. With an increase of the 'head' a corresponding increase in the pressure of steam must be provided. Thus, for lifts from 20 to 40 feet, the steam-pressure at the pump should not be less than from 20 to 30 lbs. per square inch, and for lifts from 40 to 80 feet not less than from 30 to 50 lbs.; a 50-feet lift requires 40 lbs. of steam.

The makers say the 'Pulsometer' will raise water to a total height of 100 feet with a steam-pressure of 70 or 80 lbs. per square inch. Notwithstanding the limitations imposed by the circumstances named to its application to underground drainage, occasions sometimes arise where the services of a pulsating steam-pump might be temporarily enlisted with advantage, such as in draining flooded galleries, fixing and repairing other pumps, and other work of an emergency or rescue character. No other pump can be so quickly installed in a shaft and set to work, and it can be dropped through small and confined spaces between rods, stages, timbering,

etc., where it would be impossible to pass an ordinary pump. It is remarkably free from risk of breakdowns; there are no external parts liable to fracture from falling rock, no levers, tappets, etc., that may be placed *hors de combat* by the deposition of mud or débris. Having no exhaust steam it does not heat the workings. It can handle water of any consistency, and will pass fragments of coal and rock, chips, etc., that would quickly disable an ordinary pump. For lifts exceeding 60 to 80 feet one pump may be placed above another.

We have referred to the excessive consumption of steam with this class of pumps. How serious this is the following remarks from an authority previously quoted will show:[1] 'Experiments made in Germany show consumption of 200 lbs.[2] and over of steam per horse-power of water lifted per hour. Pulsometers should be improved, if possible, by preventing condensation of the steam during its entrance into the working-chambers. It should, after filling a chamber, be condensed rapidly by some form of spray-injection like that used in the Körting Pulsometer. . . . The steam should again be prevented from condensing during the forcing pulsation. By reducing these two condensation losses to a minimum, Körting claims to have obtained results of less than 100 lbs. of steam per water horse-power per hour, which is a better result than obtained with ordinary steam-pumps.'[3]

Several patents have been taken out from time to time for pumps of this class, and for improvements thereto. Besides the original pump, known all over the world as the 'Pulsometer,' there are the 'Pulsator,' 'Aqua-Thruster,' 'Fluometer,' 'Waterspout,' and others not so well known, all modifications, more or less, of Hall's pump.

Cost.

The following tables give the prices, capacities, and other particulars of three of the leading pulsating pumps. In reference to the 'Pulsometer,' it

THE 'PULSOMETER' PUMP.

Size no.	Water per hour	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dimensions (height, width, and depth)	Price
	gallons	in.	in.	in.	in.	£
5	10,000	4	3	¾	37 × 24 × 20	32
6	13,000	4½	3½	1	42 × 26 × 22	42
7	17,000	5	4	1¼	48 × 30 × 26	55
7½	22,000	5	4	1¼	52 × 30 × 27	70
8	28,000	6	5	1½	59 × 31 × 32	80
9	40,000	7	6	1½	65 × 40 × 35	100
10	52,000	8	7	2	79 × 47 × 41	130
11½	80,000	10	9	2	98 × 54 × 49	170

[1] H. C. Behr, *Mine Drainage, Pumps, &c.*, p. 166.
[2] Equal to about 22 lbs. of coal.
[3] This is certainly an error. Whilst there may be some types of the ordinary steam-pump that will do this duty, it is very doubtful that the pulsating pump has yet been invented that will equal it, low as it is.—S.M.

THE 'PULSATOR' PUMP.

Size no.	Water per hour			Dia. of suction and delivery pipes	Dia. of steam pipe	Price
	15 feet	35 feet	65 feet			
	gallons	gallons	gallons	in.	in.	£
5	7,800	7,150	6,500	3½	¾	22
6	9,750	9,100	7,150	4	1	28
7	13,200	12,000	10,000	5	1	35
8	20,000	18,000	16,000	6	1¼	50
9	27,000	25,000	22,000	7	1½	70
10	45,500	39,000	31,200	9	2	100
11	78,000	68,900	58,500	12	2½	150

THE 'AQUA-THRUSTER' PUMP.

Size no.	Water per hour, 30 feet high, with 60 lbs. steam	Dia. of suction pipe	Dia. of delivery pipe	Dia. of steam pipe	Dimensions (height, width, and depth)	Weight	Price
	gallons	in.	in.	in.	in.	cwts.	£
5	9,000	4	3½	1	45 × 22 × 18	4¾	27
6	13,000	5	4	1¼	48 × 24 × 19	5¼	36
7	18,000	6	5	1½	62 × 32 × 22	10	47
8	26,000	7	6	1¾	69 × 36 × 25	13¾	65
9	40,000	9	7	2	82 × 44 × 35	28	85
10	65,000	10	8	2¼	84 × 50 × 40	34	120
11	100,000	12	10	2½	96 × 62 × 42	46	160
12	200,000	14	12	3			330

should be stated that the number of gallons represents the discharge on a total lift of 20 feet. The makers of the 'Pulsator' state that if the working steam-pressure be less than 45 lbs., or the height of delivery more than 60 feet, the steam-pipes must be a size larger. The capacities given for the 'Aqua-Thruster' are for a height of 32 feet with 60 lbs. steam-pressure. The pumps will lift this height with from 25 to 30 lbs. steam pressure, but will, of course, not raise so much water.

Duty.

The reference already made to the steam consumption of these pumps is, we think, sufficient. They are obviously not economical; but, in view of the fact that they are not built with any pretence to economy but rather for quickness of application, handiness in operating, and suitability for rough work, and for situations and under conditions that would soon knock up an ordinary pump, it hardly appears fair to make too deep a scrutiny into their expensive habits. When they have met the emergency and answered the temporary purpose for which they have been used, they should give place to pumps that are less prodigal of the use of steam. Apart, however, from the question of duty, it will be gathered from what has been stated that the extent to which, and the occasions when, pulsating pumps can be utilised with advantage underground are limited and infrequent.

The 'Pulsometer' Steam-Pump.

Fig. 196 is an elevation, and fig. 197 a section, of this pump. The latter shows the pump fitted with grid-valves, which are the kind employed for general work; clack-valves are occasionally used; ball-valves for pumps up to No. 4 size are sometimes employed.

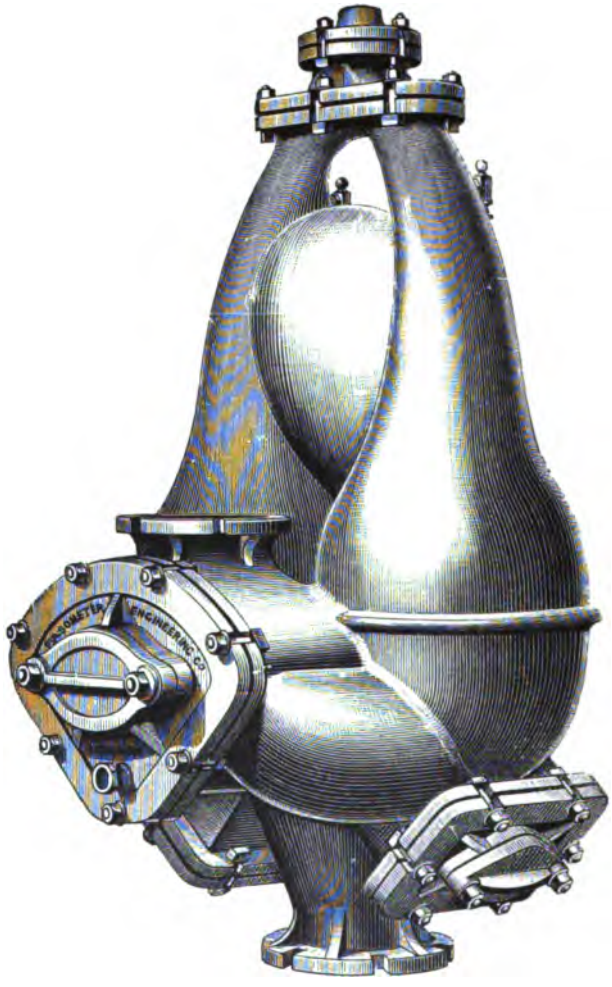


Fig. 196.—The 'Pulsometer' Steam-Pump.

The 'Pulsometer' consists of a single casting called the 'body,' which is composed of two chambers, A A, joined side by side, with tapering necks bent towards each other, and surmounted by another casting called the 'neck,' accurately fitted and bolted to it, in which the two passages terminate

in a common steam-chamber, wherein the ball-valve, I, is fitted so as to be capable of oscillation between seats formed in the junction. Downwards, the chambers A A are connected with the suction-passage wherein the inlet or suction-valves E E are arranged. A discharge-chamber, common to both chambers, and leading to the discharge-pipe, is also provided, and this also

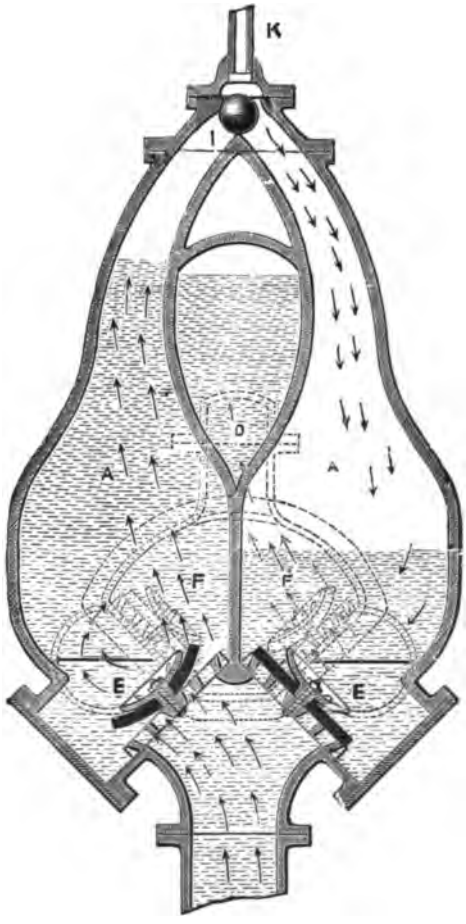


FIG. 197.—The 'Pulsometer' Steam-Pump; vertical section.

contains one or two valves, F F, according to the purpose to be fulfilled by the pump. The air-chamber B communicates with the suction. The suction and discharge-chambers are closed by covers accurately fitted to the outlets by planed joints, and readily removed when access to the valves is required; in the larger sizes hand-holes are provided in these covers. Small air-cocks (seen in fig. 196) are screwed into the cylinders

and air-chamber, for use as will be hereafter described. These are the general outlines of the construction of the apparatus, and they are sufficient for understanding the nature of its operations.

The pump being filled with water, either by pouring water through the plug-hole in the chamber or by drawing the charge, as can readily be done by attention to the printed directions, is ready for work. Steam being admitted through the steam-pipe K (by opening to a small extent the stop-valve) passes down that side of the steam neck which is left open to it by the position of the steam ball, and presses upon the small surface of water in the chamber which is exposed to it, depressing it without any agitation, and, consequently, with but very slight condensation, and driving it through the discharge opening and valve into the rising main.

The moment that the level of the water is as low as the horizontal orifice which leads to the discharge, the steam blows through with a certain amount of violence, and being brought into intimate contact with the water in the pipes leading to the discharge-chamber, an instantaneous condensation takes place, and a vacuum is, in consequence, so rapidly formed in the just emptied chamber that the steam ball is pulled over into the seat opposite to that which it had occupied during the emptying of the chamber, closing its upper orifice and preventing the further admission of steam. The vacuum is thus completed and water rushes in immediately through the suction-pipe, lifting the inlet-valve, E, and rapidly fills the chamber A again.

By the application of the 'Grel' arrangement the steam is automatically cut off, and the economy obtained by expanding the steam is stated to amount to from 25 to 50 per cent. of the total steam consumption. The increased economy effected by the 'Grel' depends on the employment of a secondary cut-off valve in addition to the distributing valve, so that a long interval may intervene between each pulsation, during which no steam can pass through the steam-pipe, although the work of pumping is going on continuously. The quantity of water thrown by 'Pulsometers' fitted with the 'Grel' is, of course, somewhat reduced, as the pump works expansively instead of taking steam the whole stroke.

The 'Pulsometer,' in common with other pumps of this class, will raise liquids in which there is a very large quantity of matter in suspension, such as brick and cement slurry, sewage, mud, and thick liquids generally, in handling which, as well as in sinking through gravel, sand, etc., it proves itself to be a hardy as well as a useful pump.

The makers are the Pulsometer Engineering Co., Ltd., Nine Elms Iron Works, London.

THE 'AQUA-THRUSTER' STEAM-PUMP.

This pump is illustrated by figs. 198 and 199. The section shows the internal arrangement. It will be observed that steam is entering the right-

hand chamber, driving the water through the delivery-valve, as indicated by the arrows. Meanwhile the left-hand chamber is filling, and by the time the right-hand chamber is emptied, the former has filled. The

FIG. 198.—The 'Aqua-Thruster' Steam-Pump.

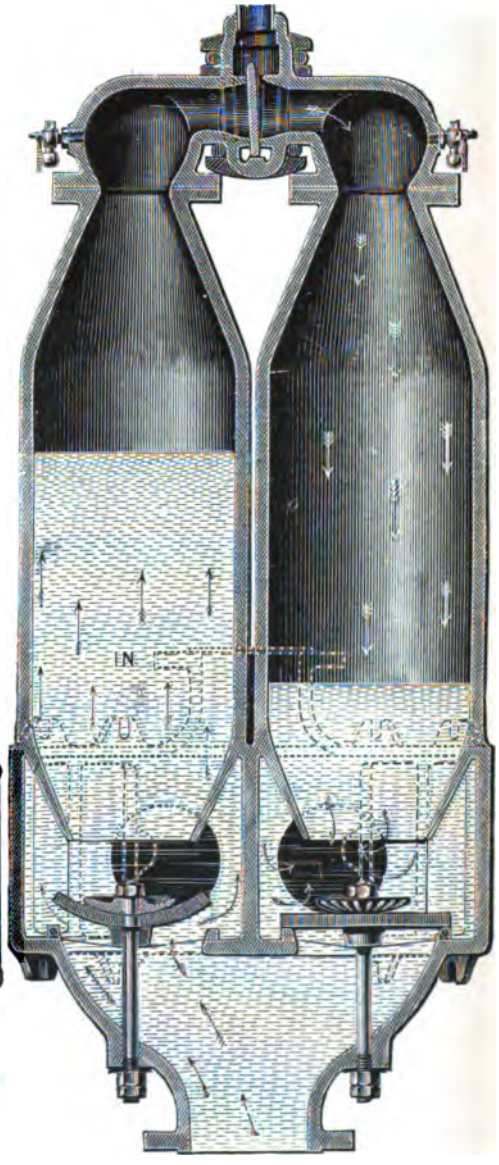


FIG. 199.—The 'Aqua-Thruster' Steam-Pump; longitudinal section.

steam-valve in the head of the pump is now drawn to the right, and the steam forces the water out of the left-hand chamber, and through the delivery-valve, and water rushes into the right-hand chamber through the suction-valve. Messrs. W. H. Bailey & Co., Ltd., Salford, Manchester, are the makers of this pump.

The 'Pulsator' Steam-Pump.

In its general features this pump resembles other pumps of the kind, but it has one peculiarity which distinguishes it from them—namely, an injection-spray for accelerating the condensation of the steam immediately

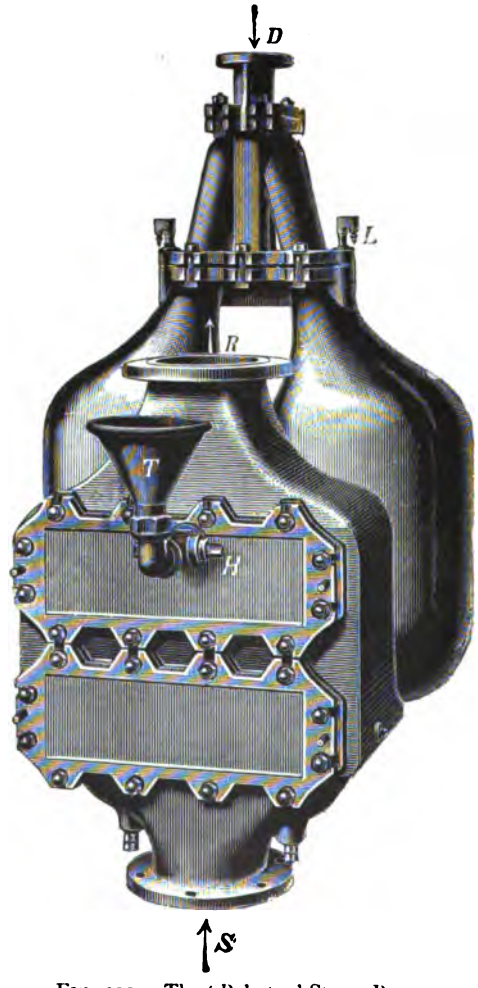


Fig. 200.—The 'Pulsator' Steam-Pump.

it is cut off. The operation is described below. Fig. 200 is a perspective view, and figs. 201 and 202 are sections. Messrs. Körting Brothers, 53 Victoria Street, London, are the makers of this pump.

The 'Pulsator' consists of two chambers of pear-shaped form, cast in one piece side by side. Bolted to the top of this casting there is a valve-box containing an oscillating clapper-valve, which opens and closes the inlet to each chamber alternately, as in the other pumps noticed, so that whilst steam is passing into one chamber, the valve closes the opening to the other, and *vice versâ*. In front of the two pump-chambers is a valve-

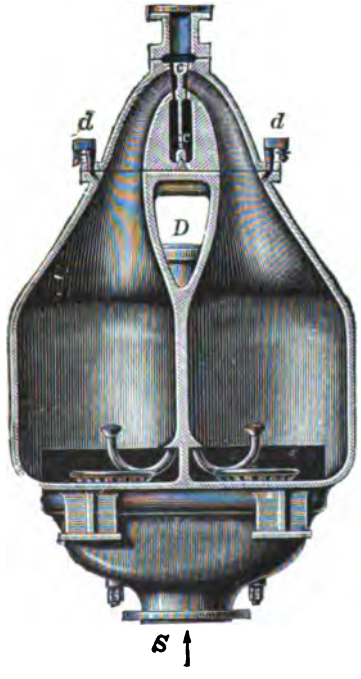


FIG. 201.—The 'Pulsator' Steam-Pump; transverse section.

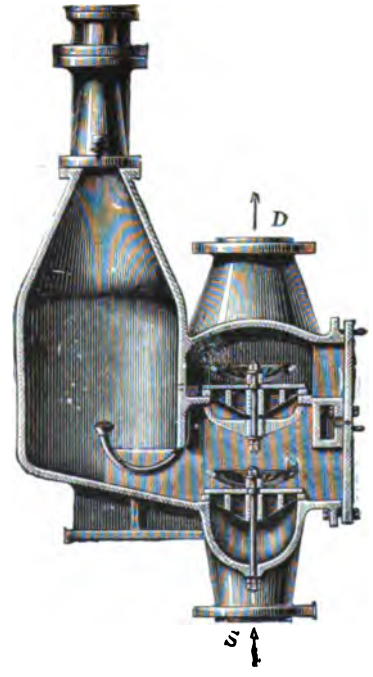


FIG. 202.—The 'Pulsator' Steam-Pump; side section.

box with suction and delivery-flanges, S and R (fig. 200), and containing a separate suction and delivery-valve for each chamber. This box has two cleaning-doors, H, for easy access to the valves. The funnel, T, on the upper cleaning-door is for priming the pump when first starting, and the small air-valves, L, ensure smooth and regular working, by admitting a small quantity of air into the chambers whilst these are under vacuum. At the bottom and in the middle of each pump-chamber there is a small injection pipe, pointing upwards, and provided with a 'rose.' These injection-pipes are in connection with the delivery-pipe, so that the pressure in the latter

sprays a small portion of water back into the chamber between each delivery-stroke.

The *modus operandi* is as follows:—The 'Pulsator' being primed with water, and the steam-valve opened, the steam enters the upper part of one of the chambers, the clapper-valve closing the opening to the other. The steam pressing on the surface of the water steadily forces the water through the delivery-valve into the delivery-pipe. Near the bottom of the pump-chamber there is a hanging ledge between this and the valve-chamber, and as soon as the water reaches this level the steam passing under the ledge agitates the surface of the water. The effect of the agitation is to cause active condensation of the steam in the chamber, a partial vacuum is created, and the clapper-valve is drawn over, cutting off further supply of steam to this chamber, and admitting it to the other. At the same time the injection spray comes into operation, fully condensing the steam in the first chamber, and so causing a fresh supply of water to flow in through the suction-pipe, whilst the water in the second chamber is being forced into the delivery-pipe. The two chambers are in this way alternately filled and emptied, and a constant flow of water maintained in the suction and delivery-pipes.

PUMP-VALVES.

PRECLUDED at an earlier stage from giving to this subject the attention its importance demanded, and debarred even now by considerations of time and space from taking more than a few steps into the domain of valve design, construction, and application, we should like, before closing the subject proper of this work, to give what little further consideration to this matter the aforesaid limitations will permit, in the hope that our observations, with the accompanying illustrations, will be of some little service to the reader.

Placed as it were in the very heart of the machine for the triple function of the alternate reception, retention, and discharge of the liquid, the valve occupies a most important position in the pump, the efficiency of which depends largely upon the proper discharge of those important duties. Badly designed and constructed valves will neutralise the good qualities of an otherwise efficient pump, if they do not actually reduce it to impotence.

It is, therefore, not surprising that pump-valves have always demanded and received the most careful attention from engineers, and numerous indeed are the varieties which have been devised from the early days when Newcomen, Watt, and other engineers began their great careers in the mines of Cornwall and the collieries of the North. Whilst they were busy elaborating their great conceptions and advancing towards the goal of perfection with their steam-engines, the humbler pitman and mining captain, down in the dark and cavernous regions with their weird and dismal echoes, to the accompaniment of rattling rods and the thunderous beats of the pump-stroke, were quietly working out the problem of better hydraulic equipments. The invention of the plunger-pole was a most important step in this direction, but it was not the only one; great improvements were made in the buckets and valves. These from the first have been of the clack type, quite a variety of which have been designed by the Cornishmen from time to time.

As we shall presently see, clack-valves are not largely used in steam-pumps, being too sluggish and cumbrous for quick-running engines with their lively action. Their special sphere of application appears to be the pump-lifts of the Cornish system.

In the necessarily brief reference to this subject at p. 82, when considering the construction of steam-pumps it was stated that the valves must

be adapted to the pump and the circumstances under which it is used. Besides the local conditions under which the drainage operations are carried out, the height of the lift, the speed at which the pump is required to be worked, the quality of the water, and the type of the engine are factors which must be carefully taken into account in designing and applying pump-valves.

From one cause or another, of a host of valves which have from time to time made their appearance only a comparatively small number have stood the severe test of work in a mine or colliery, and many of these have acquired a local rather than a general reputation, and are only to be found in certain mining districts.

Of course in such a number of valves differing in many cases so widely from each other there are qualities which are peculiar to the different valves, adapting them for use in certain kinds of engines and under certain circumstances. No valve, therefore, can be the most useful under every circumstance.

It is obvious that low lifts (such as may be found in connection with factories), with high piston speeds, and heavy mine or colliery lifts of 500 or 600 feet vertical and upwards, with a necessarily lower speed, to say nothing of the quality of the water, require very different types of valves both as regards the design and the material used. In the former case the most elastic kind of valve must be used to suit the quick reversals of the piston. The lift must be low and distributed over a large space ; in default hereof a large slip occurs. In the latter case a strong metallic valve (of gun-metal, if the water be acidulous), with springs for controlling the motion, must be employed. Here, too, the lift must be small, not only to prevent slip but to reduce the shock of the reversal of the stroke.

For both fast working and great pressures a low lift of the valve and an ample waterway are a *sine qua non*.

Brass or gun-metal valves should be used when the water handled is highly mineralised. In such water cast-iron valves are soon rendered useless, and brass valves after a few weeks generally require refacing. These difficulties have led to the adoption in some instances of valves compounded of hippopotamus hide and brass, which give much better results. Brass, bronze, gun-metal, and phosphor-bronze are the alloys that have been used for valves where the water is corrosive, but preference is given to gun-metal.

In the Cornish copper mines many years ago, particularly in the Gwennap district, where the water was very acidulous, and its corrosive effects were increased by its high temperature, it was necessary to use brass valves ; the seats were invariably stocked with birch beats, the valve being faced with leather in the ordinary way. The experiment of a wood beat in both valve and seat has been tried in the Clifford mines, Gwennap, but it was soon abandoned as useless, both beats being of too unyielding a nature to compensate for inequalities in their surfaces, thereby causing leakage. Tin

as a beating material was also tried, but was found to be far inferior to wood, soon becoming corrugated. Rows of leather on its edge let into the valve, and planed perfectly level, were another venture, about the year 1833, and answered fairly well; better in drawing from a 'still pool' than in progressive work, where gravels cut the leather, got imbedded in it, and caused leakage. India-rubber, tried as a substitute for leather, proved most unserviceable, as the water made it rotten and the edge of the seat soon cut it through.

Hippopotamus hides were once used at the mines named, and were extremely durable. They gave great satisfaction, and would have entirely superseded leather but for the difficulty of obtaining a sufficient supply. In the Severn Tunnel pumping works poplar has been found to be a useful beat. The beats for the Harvey & West valve are a composition of tin and lead which is run into a dovetailed groove in the seat. A similar alloy is used for the beats of Husband's valve.

The loss of useful effect by slip or back-flow of the water varies from about 3 to 10 per cent. of the water pumped, according to the design of the valve and the circumstances under which it is used. Well-designed valves do not lose more than from 3 to 5 per cent. by slip; clack-valves used with short-stroke engines at high speeds have been known to lose as much as 10 per cent. Working under a head of 1,341 feet, double-beat valves of the Harvey & West type at the Woodpark Colliery have a slip of only 3·6 per cent.

To minimise the slip the valve should have a low lift and close as rapidly as possible the moment the pump-stroke is reversed. The former is secured by providing an ample waterway. In the 'Selden' pump the valves are made so large that by lifting from $\frac{3}{8}$ inch in the smaller sizes to $1\frac{1}{4}$ inch in the larger sizes they will give the full capacity of the suction and delivery-pipes.

Increasing the number of openings, and thereby the area of the waterways, as in Harvey & West's and Husband's valves, conduces to lowness of lift. Promptness of closure is secured mechanically by the use of rubber or metallic springs. When rubber springs are used a small free lift is given to the valve, generally $\frac{1}{8}$ inch; the remainder is obtained by compression of the rubber. In any case stops should be provided to limit the rise of the valve, but it is always advisable for it to lift against an elastic buffer, as not only will it control the rise but accelerate the return of the valve to its seat. In corrosive water metallic springs would not be serviceable, and rubber springs should be vulcanised and of the best quality. In either case under the circumstance named new springs would be needed frequently. In heavy Cornish lifts, with highly mineralised water, often of considerable temperature, we do not think springs would be of any use except for a brief period.

Broadly speaking, valves may be divided into two groups, viz. *Metallic Valves* and *India-Rubber Valves*, and, without entering into minute

details or regarding subtle distinctions, and noticing those that are more curious than useful, the groups may be subdivided as shown below:—

I. METALLIC VALVES.

1. *Clack-Valves.*
   - *a.* Ordinary Clack-Valves.
   - *b.* Clack-Valves with contrivances for facilitating the exit of the water.

2. *Valves with a vertical lift.*
   - *a.* Ball-Valves.
   - *b.* Single-Beat Valves.
   - *c.* Double-Beat Valves.
   - *d.* Treble-Beat Valves.
   - *e.* Quadruple-Beat Valves.
   - *f.* Multiple Valves.

II. INDIA-RUBBER VALVES.
   - *a.* Ball-Valves.
   - *b.* Flat Valves.
   - *c.* Conical Valves.
   - *d.* Lip-Valves.

I. METALLIC VALVES.

1. CLACK-VALVES.

a. Ordinary Clack-Valves.

These are hinged to the seat either with rivets or bolts or with a pin, each end of which works in a recess or slot. In the latter case the valve

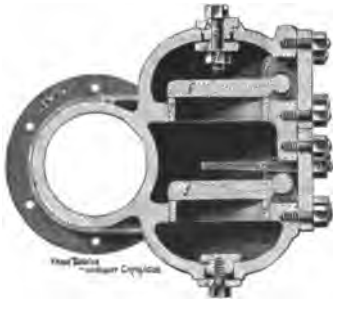


FIG. 203.—Clack-Valves (Iron or Brass, faced with Leather). 'Special' Steam-Pump.

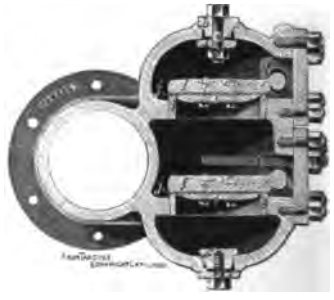


FIG. 204.—Clack-Valves (Iron or Brass). 'Special' Steam-Pump.

lifts a little at the hinge. There are several varieties of these valves known in the Cornish mines, where scarcely any other kinds are used, as the Butterfly, Hake's Mouth, Jan Ham's, and Trelease's. Wherever the

Cornish system of pumping prevails clack-valves of one or another of these types are almost exclusively used. They are sluggish in their action, with much concussion in closing, owing to the high lift, and consequently are not well adapted for steam-pumps. Figs. 203–205 are illustrations of

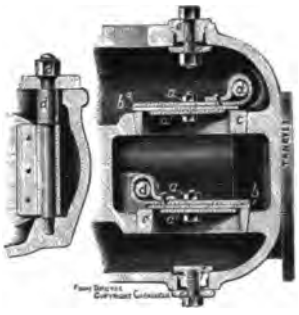
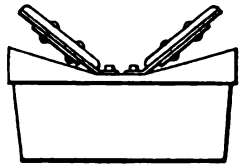
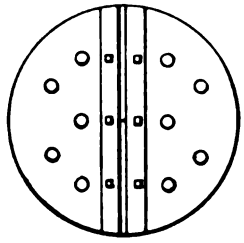


FIG. 205. — Sewage Valves (Wrought Iron). 'Special' Steam-Pump.





FIGS. 206, 207.—Butterfly Valve; elevation and plan.

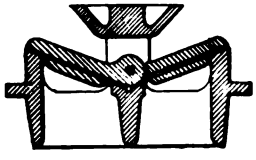
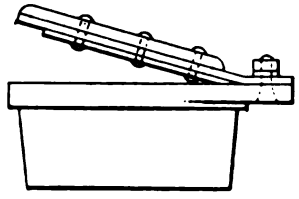
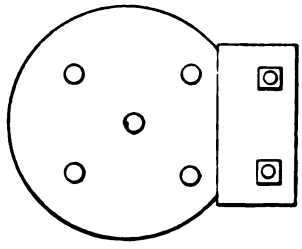


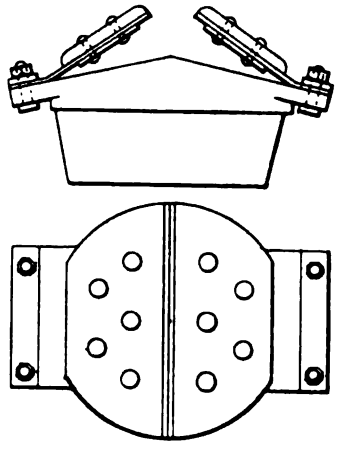
FIG. 208.—Butterfly Valve; section.



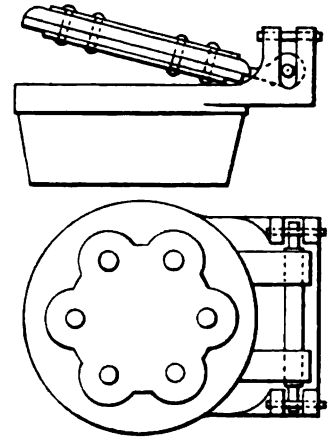


FIGS. 209, 210.—Hake's Mouth Valve; elevation and plan.

clack-valves used with some types of the 'Special' steam-pump. Figs. 206 and 207 and 209 to 214 inclusive are reproduced from Michell and Letcher's 'Cornish Mine Drainage,' and are elevations and plans of the four types of valves named above respectively.

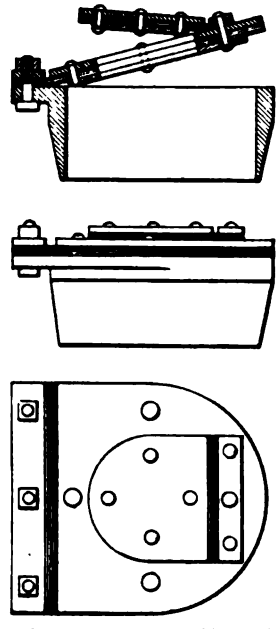


FIGS. 211, 212.—Jan Ham's Valve; elevation and plan.



FIGS. 213, 214.—Trelease's Valve; elevation and plan.

b. Clack-Valves with contrivances for facilitating the exit of the Water.



FIGS 215-217. — Teague's Valve; section, elevation, and plan.

Mr. Henry Teague's Noiseless valve (figs. 215–217) consists of the ordinary Hake's Mouth variety, with the central portion removed and a small valve hung, in an opposite direction, over the opening. Mr. Teague also originated a clack-valve with a series of perforations over which circular pieces of india-rubber work (on a spill working through the central hole of each series). Jenkyn's valve consists of three clack-valves, over each other. Valves on the principle of Mr. Teague's noiseless valve have given much satisfaction; they are a great improvement upon the ordinary clack-valves, and ought to supersede them in heavy pump-lifts.

2. VALVES WITH A VERTICAL LIFT.

a. b. Single-Beat Valves.

This class comprises ball, cup, wing, mitre, and mushroom-valves. The first consists of a metallic ball which works within a framework to prevent its being thrown out of its place. The cup-valve (fig. 218) is a short cylinder closed at the top, which slides within the seat, and has vertical orifices.

The wing-valve (figs. 219–222) consists of a flat or a rounded circular piece, surmounting a number of radial arms or wings which act as guides. Mitre and mushroom-valves differ principally from the wing-valve in the form of the valve, the seat and guides being similar.

All these valves have a high lift. With the exception of the ball-valve

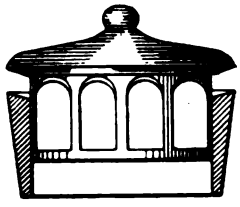


FIG. 218.—Cup Valve.

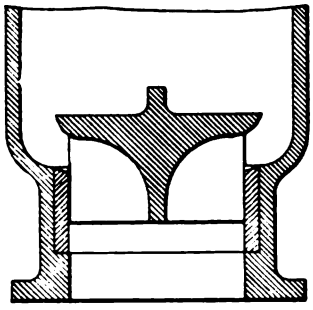


FIG. 219.—Wing Valve.

they are suitable for light lifts. For working at a high speed they should be fitted with an india-rubber spring, to control the lift and accelerate closing, and have a large area in proportion to the working barrel to reduce the lift. For mine or colliery pumps up to 10 inches diameter the best valves are the wing and mitre-valves, made of gun-metal with lignum vitæ beats, and an india-rubber spring on the top. In his 'Salford' pump

FIG. 220.—Wing Valve (Brass). 'Special' Steam-Pump.

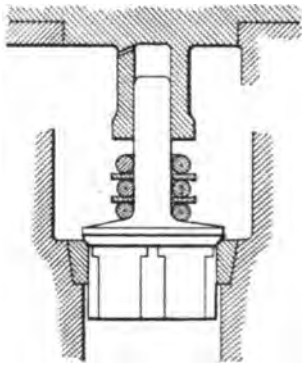


FIG. 221.—Wing Valve.

Mr. Turner used a mushroom-valve. Mr. John Cameron also uses this kind of valve in his vertical rotary ram-pumps.

Mitre-valves, with rubber springs, are used in the Self-Governing engines of Messrs. Hayward-Tyler & Co., and in some varieties of the 'Universal' pump, and in the 'Caledonia,' and Messrs. Parker and Weston's and Turner's engines of the same class. Colebrook used wing-valves in

his pump, of which fig. 222 is a section, and in the Self-Governing Plunger-Pump valves of this description with india-rubber springs are used: see fig. 105. In the Worthington plunger-pumps brass valves,

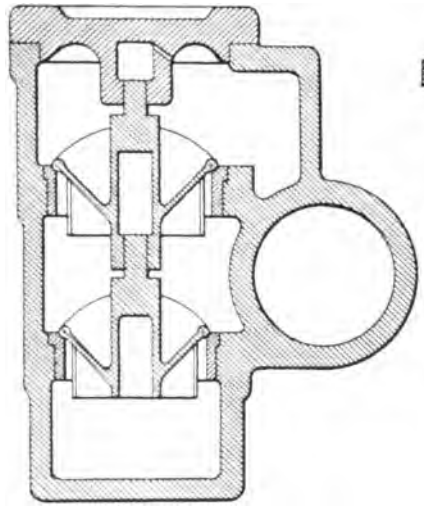


FIG. 222.—Wing Valves; Colebrook's Steam-Pump.

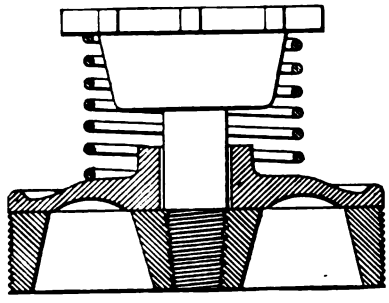
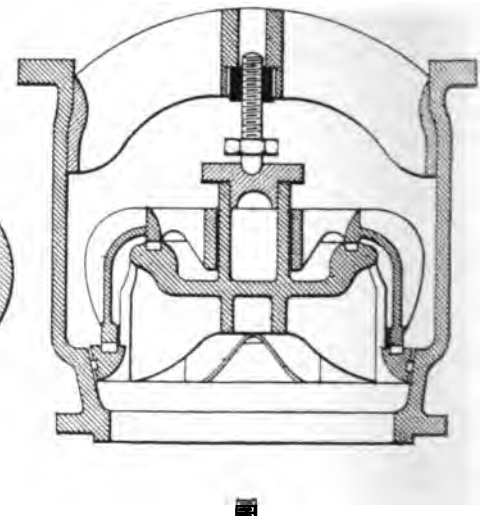
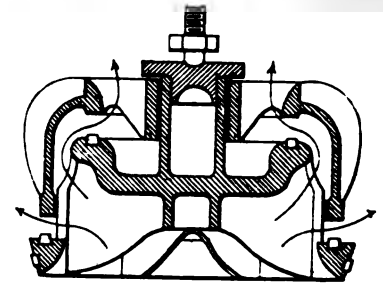
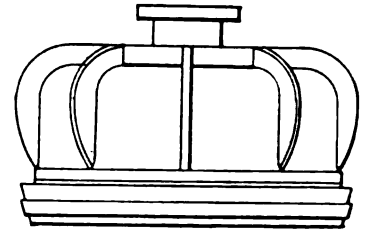


FIG. 223.—Spindle Valve; Worthington Steam-Pump.







FIGS. 224–226.—Harvey & West's Double-Beat Valve; sections and elevation.

fig. 223, are employed, faced with leather, guided from below by wings, and controlled by composition springs. See also figs. 112, 113, and 118.

c. Double-Beat Valves.

The best type is the well-known Cornish Valve, Harvey & West's, of which figs. 224 and 225 are vertical sections, showing the valve closed and open respectively; fig. 226 is an elevation. Valves of this type have a large lifting area, spacious waterway, and consequently a low lift; there is, therefore, little concussion, and the slip of water is very little. They are largely used in waterworks, but are not suitable for ordinary sinking-pump-lifts, owing to the solid impurities in the water which get between

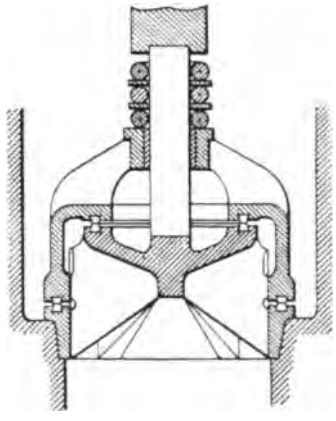


FIG. 227.—Harvey & West Double-Beat Valve.

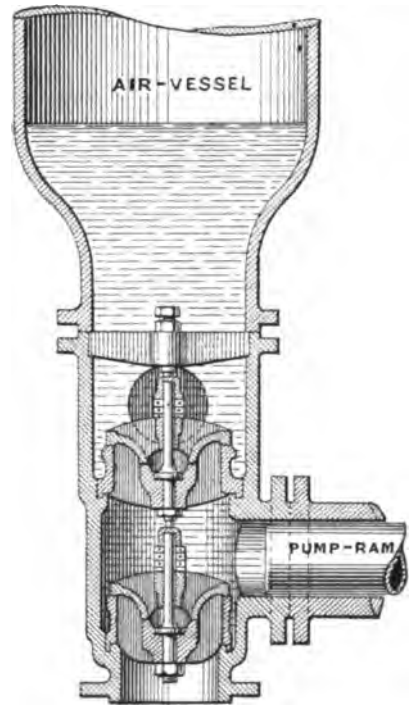


FIG. 228.—Harvey & West Double-Beat Valve.

the beats and thus disable the valve; they are not used in Cornwall. For a high rate of speed they should be fitted with an india-rubber spring to secure a prompt closing. Figs. 227 and 228 are modifications of the Harvey & West double-beat valve, fitted with rubber springs; the latter shows one way of securing the seat. Mr. Henry Davey states that valves (Harvey and West's) with the bottom beats of gun-metal and the top ones of hippopotamus hide have been at work for twelve months under heads of 600 to 1,000 feet in dirty water without new leather beats being required. Valves of this kind are used with Davey's 'Differential' engines. Mr. Davey

has found by experiment that the slip with these valves is 7½ per cent. less than with the ordinary butterfly-valves. Rhinoceros hide is said to be very durable, and when let into the seats of the ordinary double-beat valve makes one of the best and most durable of valves, but it is expensive.

At Woodpark Colliery the valves and seats are of cast-steel. On the face of the valve a lip is turned, and corresponding to it a recess in the seating, which is filled with woodite, which procures a silent action and a

FIG. 229.—Spindle-Valves (Brass) with Springs. 'Special' Steam-Pump.

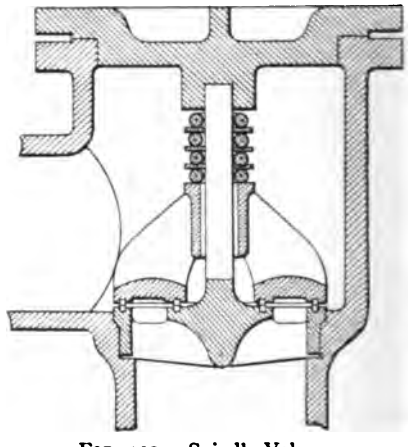


FIG. 230.—Spindle Valve.

perfectly tight face, under a head of 1,341 feet. Figs. 229 and 230 are sections of valves of another type belonging to this class, fitted with springs. The former are extensively used by Messrs. Tangyes, Limited, in the Special' Steam-Pump (300 and 600 feet series).

d. Treble-Beat Valves.

Valves on the same principle as that of Harvey and West's have been constructed with three beats. Messrs. Carnell and Hosking introduced a valve of this class (fig. 231) many years ago, but it does not appear to be in use. They are not suitable for mines or collieries.

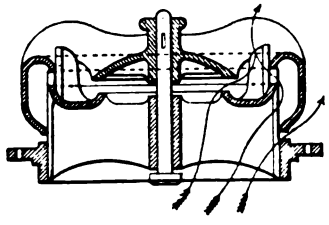


FIG. 231.—Carnell & Hosking's Valve; section showing valve open.

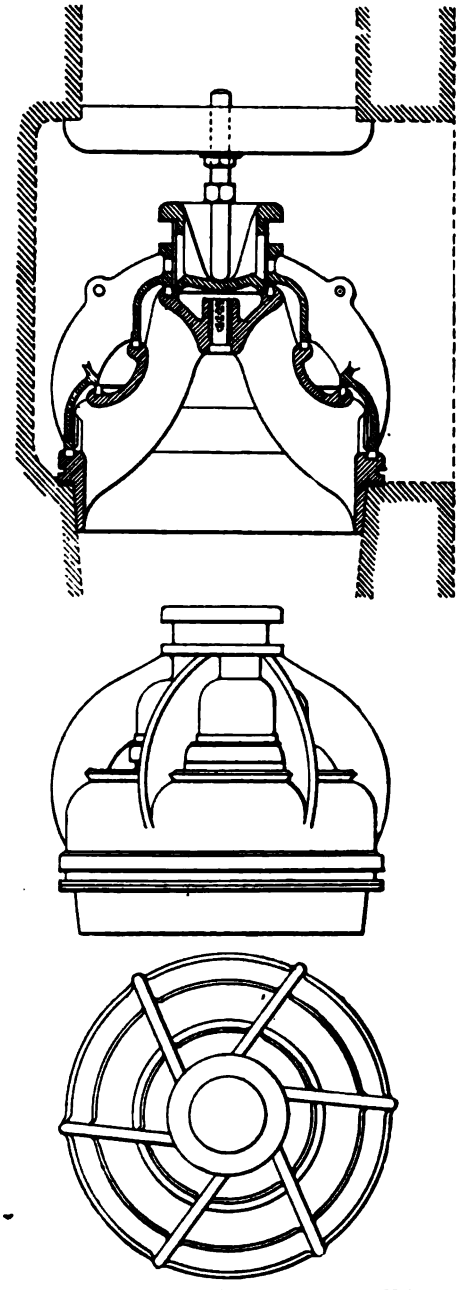
e. Quadruple-Beat Valves.

Husband's four-beat valve (figs. 232–234), designed by the late Mr. William Husband about the year 1863, is a further extension of the principle carried out in the last two classes named. It is well adapted to waterworks purposes, but is not suitable for mine or colliery work unless the water is clean and free from grit. 'Some of these

engines' (direct-acting) 'used for pumping water for the supply of towns make the up-stroke of 10 feet in a second with poles reaching a diameter of 50 inches, and this valve allows the water to pass with such freedom that the valve is closed at the moment the up-stroke is completed, and there is consequently no loss of water or shock. About sixteen years since the writer made valves on this principle for a pump for pumping water from a depth of 320 yards in one lift, at the Eagle Bank Colliery, Yorkshire, and they acted without shock under that great head of water, and are at work to the present day.' [1]

At the Severn Tunnel pumping works, Sudbrook, where several Cornish engines are at work, made by Harvey & Co., Ltd., Hayle, and where from 20 to 28 million gallons of water are raised daily, varying with the seasons, Husband's valves are largely used; they are 34 inch and 35 inch diameter, with a lift of 3 and 3½ inches respectively. At 9 strokes per minute there is scarcely any noise. Mr. Richard Hosken, to whom the author is indebted for this information, says (Dec. 17, 1888): 'The valves are practically perfect; after stopping a

[1] William Husband, C.E., 'Pumping Machinery,' *Proceedings of the Mining Inst. of Cornwall*, vol. i. No. 5, p. 167.



FIGS. 232-234.—Husband's Four-Beat Valve; section, elevation and plan.

month they will often discharge water at the first stroke when again started to work. All the valves used here are Husband's four-beat (gun-metal), with the exception of the delivery valves of 26-inch plungers. We are now using cast-iron double-beat valves there with poplar wood seats; lift 4 inches. We started one of these 26-inch plunger-pumps to-day after standing idle a little over a month, and at the first stroke it discharged water.'

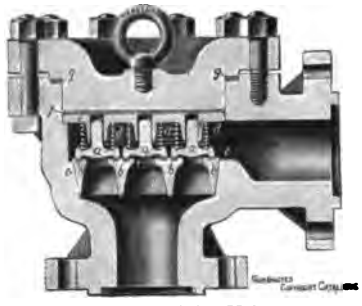


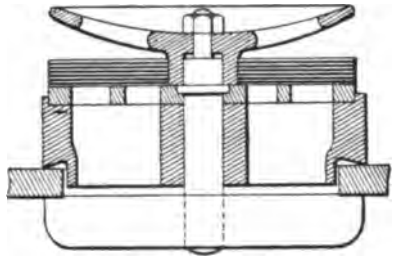
FIG. 235.—Multiple Valves (Brass) with Springs. Section 'Special' Steam-Pump.

f. Multiple Valves.

For very heavy pressures multiple valves—a number of small metal valves—as fig. 235, have been found very useful. The illustration represents valves used in the 'Special' double-ram pump, 1,000 feet series.

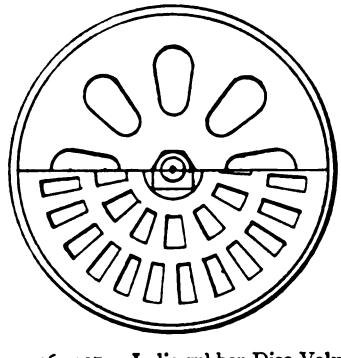
II. INDIA-RUBBER VALVES.

a. Ball-Valves.



These have been found useful for low lifts and quick-running pumps, but are of no service in heavy lifts. In the 'Universal' pump, solid rubber ball-valves have displaced the disc-valves; see figs. 90, 93, 94. For greater heads than 200 feet the gun-metal mitre-valve is used.

b. Flat-Valves.



FIGS. 236, 237.—India-rubber Disc-Valve; section and half-plan of guard and grid.

These valves, known as rubber disc-valves, consist of a flat circular piece of india-rubber fastened at the centre to a grating or grid, which forms the seat of the valve. Unless protected by a metal case, as in the valve used in the 'A. S. Cameron' pump, they are not adapted for greater heads than about 350 feet. Obviously the apertures of the grid must be smaller for medium lifts than for light lifts. Figs. 236 and 237 are a section and half-plan of

guard and grid of a valve of this kind. Fig. 238 is the valve used in the 'Special' steam-pump. Fig. 239 shows the 'Cameron' valves referred to; they are made of a casing of brass filled with india-rubber. The latter forms the valve-face, and the metallic casing resists the pressure and

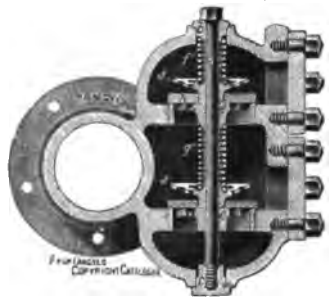


FIG. 238.—India-Rubber Disc-Valve with Springs. 'Special' Steam-Pump.

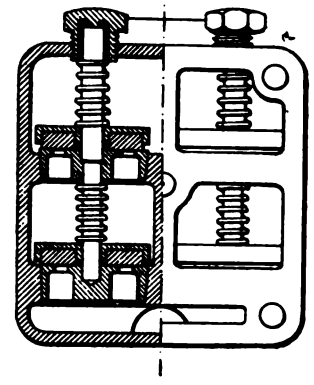


FIG. 239.—India-Rubber Valves (Brass-cased) with Springs. A. S. Cameron Steam-Pump.

protects the rubber from injury. Thus protected they will stand very heavy pressures. Metallic valves are also used in the 'Cameron' pump, as well as other kinds of valves, depending on the lift, nature of the fluid to be pumped, etc.

In the 'Cornish' steam-pump Messrs. Jos. Evans & Son use rubber disc-valves, the seats for which are of gun-metal; see figs. 174 and 176. A rotary motion is imparted by the slanting inclination of the apertures in the seat, impinging the water against the valve obliquely; this promotes its durability. Many years ago Mr. George Massey designed an excellent valve with oblique waterways, which were successfully used for heads of 300 feet. Valves of best vulcanised rubber are used in the 'Knowles' pump for medium pressures. In the 'Blake' pump the valves are made of the best quality rubber, and the seats of heavy gun-metal composition. Mr. Massey has also designed a valve with four small revolving discs on one grid; to accelerate the closing, india-rubber springs are sometimes applied to the flap. Mr. Holman has introduced a valve consisting of a rectangular grid covered with round bars of india-rubber fastened at the ends with glands. Mr. Thomson is the designer of a novel flat-valve, in which the grid is dispensed with; there is an annular piece of india-rubber, which first gives exit to the water by the bending upwards of its edges, and as the pressure increases the valve is lifted bodily.

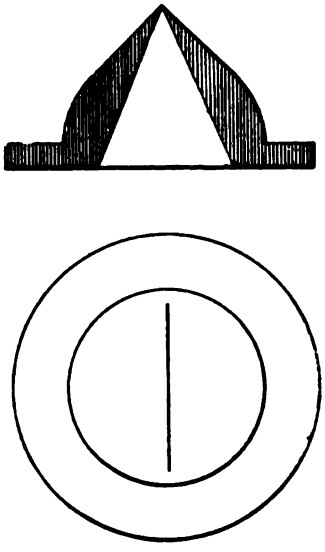
In the 'Cornish,' 'Blake,' and 'Knowles' sinking pumps india-rubber disc-valves are used; see figs. 181 and 184. Valves of this kind are also used in the 'Aqua-Thruster' pump (fig. 199).

c. Conical Valves.

These valves consist of a perforated cone wound around which are bands or rings of india-rubber. In some valves the water escapes by distension of the india-rubber, in others by its compression. Mr. Morris's pyramid or hatband-valve consists of several short cylinders, in one casting, diminishing gradually from the bottom to the top. Around each cylinder is a band of india-rubber, fastened at the bottom by an iron clamp. They can be used for pressures not exceeding 200 feet. The collective areas of the holes are one and a half times the area of the pump. The respective pumps of Mr. Holman, Mr. West, and Mr. Morrison are on the same principle, but different in construction. In Hoskin's ball-valve a series of india-rubber balls are arranged in circles on a cone. Some valves are a combination of the disc and the cone—the former surmounting the latter.

d. Lip-Valves.

These are made wholly of india-rubber. The principle involved is the forcing open of a slit in a cone or the forcing apart of two or more pieces of rubber where their edges meet by the pressure of the water, and the closing of the same by the natural elasticity of the material.



FIGS. 240, 241.—Perreaux's Lip-Valve; section and plan.

Field's disc lip-valve is composed of two flat or slightly coned india-rubber discs placed face to face horizontally. The central portion is removed, and the inner edge of each piece is firmly fixed into a groove in the main body of the pump, in such a way as to cause the discs to impinge at their outer edges. The arrangement may be fairly conceived by placing two saucers together, the top one being inverted. The water enters through the orifice in the centre of the bottom disc, and finds an exit by forcing open the discs at the outer edges. Mr. Field has also designed a compound-valve on the same principle, consisting of three lips. Perreaux's valve (figs. 240 and 241) is a flanged tube of india-rubber flattened at the top, thus forming lips.

Valves of this class are only suitable for low lifts.

ADDENDA.

Condensation of Steam in Pipes Underground.

Page 91 (*footnote*).—In further reference to steam condensation at the Drum Lummon Mine, Montana, Mr. C. W. Goodale says:—'The steam-line from the boilers through 1,000 feet of tunnel to the top of the 1,200-feet shaft has a diameter of 10 inches, and at the shaft there is a double 20 by 48 inch hoisting engine which is run from this line. Branch lines 4 and 5 inches in diameter go down the shaft to the two Riedler pumps.' 'With the variable duty of an engine hoisting from several levels, there is hardly any chance of determining how much steam it requires.' '. . . the gauges only show a pressure loss of 2 lbs. between the boiler and the pumps. The actual weight of a column of steam 1,200 feet high is an important factor in this loss of pressure question. The steam-pipes are of wrought-iron.' [The master mechanic is of opinion that the loss of power is very considerably more than that stated.]

Page 99 (*footnote*).—At Mansfield, Crystal Falls, Michigan, Mr. F. Scadden uses a wood casing for the steam-pipes to reduce condensation. His experience is that in wet shafts magnesia, felt, and asbestos absorb and retain the water, and cause increased condensation. He employs 4, 6, or 8 inch plank, according to circumstances, ploughed out sufficiently deep to go half round the pipe, and by bolting together two such pieces he completely envelopes it. The ends of the timber are cut in a manner that will carry off the water. The loss by condensation is $\frac{7}{16}$ per cent. per 100 feet. The device is a very good one, and the credit of first introducing it appears to belong to Mr. Scadden.

Davey's Compound Cornish Engine.

Page 96 (*footnote*).—The Davey engine at the Basset Mines was set to work on May 4, 1899, the starting ceremony being performed by Mrs. Basset, wife of the lord of the mines. The event marks a striking departure in Cornish pumping machinery, and deserves being chronicled on account of its practical importance and historical interest. 'The Engineer' of May 12, p. 471, gives an illustration of the engine, and *inter alia* says: 'It is now worked with a very heavy load on the piston, equal to 30 lbs. water load per square inch of the low pressure cylinder, or, say, 34 lbs. indicated, which Mr. Davey considers too high for the best economy.' 'The Cornish Post and Mining News' (May 6) gives a good description of the engine, and reports at some length the interesting proceedings, and the speeches of leading Cornish mining authorities and

Mr. Henry Davey of London, the well-known engineer, and himself a Cornishman. The salver presented to Mrs. Basset bore a design of the new engine, with the information that it had cylinders of 40 inches and 80 inches diameter, 18-inch pumps, with 13-feet stroke, and a boiler pressure of 150 lbs. per square inch, and was inscribed: 'From the directors of the Basset Mines, Limited, to Mrs. Basset, of Tehidy, on the occasion of the first application of high pressure steam to the Cornish pumping engine, and as a memento of starting the same at the official opening, May 4, 1899.' The starting of the engine was most successful. Its quiet and easy action was much admired, and local engineers and agents have formed a high opinion of the excellence of the new engine.

Husband's Four-Beat Valve.

Page 320.—With the new pitwork at Marriott's shaft, Basset Mines, in connection with the new Davey engine, gun-metal valves and seats of this class are used. They are of 18-inch diameter, and have beats of well-seasoned oak, and are used in lifts of 60 fathoms, and 18 inches diameter. At Rio Tinto Mines, Spain, Husband's valves are also used, made of an alloy of copper, lead and tin.

APPENDIX

HYDRAULIC PUMPING ENGINES

A COLUMN of water having at its base a pressure of a certain number of pounds to the square inch, which we will assume for example to be 400, and the area of the column 25 square inches, gives the same aggregate force as another column of water where the pressure is 204 and the area 49. In other words, a column of water 5 inches in diameter and 921 feet high is equivalent in total pressure to a column 7 inches in diameter and 469 feet high.

Now if the power stored up in the smaller but higher column were imparted to a pump-ram, and this brought to act upon the other but larger pump-ram under the pressure of the larger but lower column, they would be in equilibrium, the first under a head of 400 lbs. to the square inch, and the second under a head of 204 lbs. For the moment we will not take friction into account. Now it is obvious that at every pump stroke there will be delivered to the height named, 469 feet, a quantity of water equal to the displacement of the larger ram. This, simply and crudely stated, is the principle of water lifting by hydraulic pressure.

More concisely expressed, this principle of pumping by hydraulic power is the transmission of the pressure of water from a high level to a pump motor at a lower point for the purpose of raising a larger quantity of water against a less pressure. When a natural supply of water of adequate quantity is unobtainable a steam engine must be employed to furnish the necessary pressure through, of course, the intermediary of a column of water.

'There are many situations in which a small quantity of water supplied under a considerable pressure can be profitably employed to pump a greater quantity of water against a less pressure. In dip workings in collieries, for instance, engines thus worked can be advantageously used to raise water to the main pumping engines, the motive water in this case being supplied from the rising-main of the main engine. In hilly mining districts, too, water drawn from a high level may be conducted by pipes into the mines, and then used to raise a greater quantity of water to the surface, thus avoiding the necessity for steam-power.'

In the absence of a natural reservoir of power hydraulic pumps are operated by either direct-acting engines or geared engines. Where the hydraulic pump is used as an adjunct to a steam pumping engine, the latter supplies the necessary power. The method of doing this varies according to the system of hydraulic pumping adopted.

The hydraulic engine used as an adjunct to an underground steam pumping engine finds useful application in situations where the latter would be liable to submergence if placed within suction reach of the water, by a breakage of the engine or by the incursion of a flood into the workings of the mine.

Provision against the 'drowning-out' of underground steam-pumps is often made by duplicating the pumps, placing one in reserve in a 'station' some distance up the shaft ready for immediate use should the lower pump give out. This prevents the further encroachment of the water, and gives time for another pump to be sent down, and, both pumps being kept at work, the threatened disaster to the mine is averted and the workings recovered.

As we have already pointed out, this arrangement is carried out in many instances, not merely as a precaution against flooding, but as a useful method of employing steam-pumps. The main engine is located in a station, and a smaller engine working at or near the sump forces to the main engine, which not only deals with this water, but any that may come from higher levels.

The following are the principal points in favour of hydraulic pumps, viz.:

Avoidance of the inconvenience of taking steam down the shaft and into the workings, and loss by condensation.

In a temporary emergency the pumps can work under water.

In inclined shafts and dip workings the power pipes may be led round any number of bends, and any fall from the roof or sides would not readily derange the working.

An attendant underground not required.

When used for perpendicular pumping they can be placed at the side of the shaft, out of the way, requiring only space in the shaft for the rising column and the small power pipes.

Pump-rods are dispensed with.

For draining dip workings in which a steam-pump cannot be conveniently fixed, or where a bad roof renders the engine and steam-pipes dangerous, they are indispensable.

For galleries and other points subject to inundations, and for conveying power to several workings at a distance from the shaft, hydraulic pumps are specially useful.

Applicable to sinking shafts, the pump being readily moved up and down in stages as the water is lowered.

Having thus given these pumps credit for their favourable features, we must now consider what may be said on the other side. The chief objection is the low percentage of useful effect, and therefore the low duty attainable.

In two instances given a few pages further on the useful effect was only 66 and 40 per cent. respectively. In another example we have 54·2 per cent. In the Moore engine the amount is 68 per cent. Kaselowsky claims much better results for his system, the useful effect attained being stated as 77 per cent. Under normal conditions, it would appear hydraulic pumps in this country do not give on an average more than about 60 per cent., which is very low compared with Cornish and Davey engines giving from 80 to 85 per cent.

It is obvious that the two losses—namely, in engine efficiency and pump efficiency—must result in a very low duty compared with surface engines, although it would seem when working under the most favourable conditions, putting the most economical form of rotary engine to drive the pumps, as good results can be obtained with this system as with underground steam-pumps of the simple class. The manager of the Shott's Iron Company's mines states that the substitution of Moore hydraulic pumps for steam-pumps driven

by steam taken down the pit and dip mines led to a monthly reduction in the coal consumption from 859 to 567 tons.

The best known pumps of this kind in this country are those of Davey, Moore, and Joy; in the continental coalfields Kaselowsky's pump has come to the front in the last few years. The pioneers would appear to be Jordan and Darlington, who in the year 1866 patented engines for raising water by hydraulic pressure. Mr. William West afterwards became associated with Mr. Darlington in the introduction of these machines.

JOY'S HYDRAULIC PUMPING ENGINE

The following remarks on Joy's patent hydraulic pumping engine, with an account of its employment at the Grassmore and Clay Cross collieries, will be interesting as showing the circumstances under which engines of this kind may be used with advantage.

'At Grassmore colliery the water is raised from the sump to the surface by two 15-inch lifts or pumps, of 60 yards each, standing side by side, and worked by a 60-inch Cornish engine, with a 10-feet stroke, and 9-feet stroke in the pumps. The dip water was formerly raised by horizontal plunger-pumps placed in the dip workings, which were worked by wire ropes attached to the main-rod of the large pumping engine, forcing the water from the dip workings, up the rising-main, into the sump at the bottom of the shaft. The constant stretching of the ropes, and breakages therefrom, caused such frequent hindrances that it became necessary to change the system and instal a pair of hydraulic engines. The 15-inch pumps delivered from the sump into the condensing cistern of the large Cornish engine, for the purpose of supplying the condenser with cold water, and it then flowed freely away. A portion of this is now taken down again into the mine, from whence it came, to supply the motive power to the hydraulic pumping engine. One end of each pressure pipe conveying the water down to the hydraulic engines is projected a few inches into the condensing cistern, about two feet from the top; a large cullender or grate is placed over the end of each to keep out dirt, wood, and ashes, which are sometimes brought up with the pit water. They are taken down the vertical shaft about 60 yards, then turned in the direction of the dip of the coal, and, after crossing the levels, one is taken down the engine plane, and the other down the pump-head to the receiver, and from thence to the engines.

'About 100 yards below the engines in the pump-head is the lodge where the dip water is collected, and from whence it is pumped. The suction pipes are 6 inches diameter, laid in the pump-head. The engines and pumps are placed horizontally, side by side, on the same frame, at a distance of about 660 yards from the sump at the bottom of the shaft. The pumps draw their water from the same suction pipe, and force it into the ascending delivery pipe: each engine exhausts its water into the one delivery pipe; in other words, the water which propels the engines, and that which is pumped from the lodge, are together forced up the same rising-main and delivered into the sump.

'The cylinders and the pumps are of equal capacity, being 8 inches diameter, 18 inches stroke. The pumps are double-acting. The pistons of each cylinder and pump are attached to a common rod. The suction valves are placed below, in connection with the suction pipe; and the holding valves immediately over

the pumps, and communicating with the rising-main. The cylinder has ports similar to those in a steam engine, a slide-valve (made of hard wood, guaiacum or lignum vitæ) working over the top thereof. The slide-valve is moved by its connection with a double piston, moving in two short-bored chambers, in the ends of the valve-box. The double pistons are actuated by water pressure, let into and out of the bored chambers alternately by a four-way cock to which motion is given by a lever and rod, which are coupled to an arm on the piston-rod. This rod is fitted with tappets for adjusting the action of the four-way cock. All the working parts of these engines and pumps are capped with brass. The piston of both cylinders and pumps are similar in construction. Each piston is packed with two leather cups, having a brass collar between them. The whole is bolted down to a strong wood frame. A sluice-valve is placed on the inlet pipe to turn the water on and off.

'The action of the engine is as follows: When the sluice-valve is opened on the inlet pipe, the water enters through the port into the cylinder, and, pressing upon the piston, pushes it to the other end. Just before it arrives at that point, the lever of the four-way cock is caught by the tappet which is moved by the piston-rod, the motion is reversed, and the piston is brought back again, and so on, alternately. The performance of one of these engines may be expressed thus: The cylinder, 8 inches diameter and 18 inches stroke, contains in round numbers 6½ imperial gallons. If 100 gallons of water be taken down from the surface per minute, it will produce 16 strokes per minute of the engine and pump, and force up 100 gallons from the lodge in addition to that taken down to work the engine, making 200 gallons per minute delivered into the sump, the speed of the piston being about 50 feet per minute; or, the duty may be expressed thus: The total vertical head is 258 feet, the length of the pipe through which it passes 2,160 feet. This, making an allowance for friction, gives 108 lbs. per square inch. The height to which the water is delivered is 75 feet, the length of pipe through which it is forced 1,866 feet; this, with the friction added, will give a back pressure of 43 lbs. per square inch. Then 108 − 43 = 65 lbs. per square inch available pressure to work the pump. The area of the cylinder = 50·26 inches × 65 = 3,267 lbs. pressure in the cylinder, and 50·26 × 43 = 2,161 lbs. pressure in the pump, thus giving about 66 per cent. of duty.

'This would give the large pumping engine an extra quantity of 100 gallons per minute, but as its average speed is about three strokes per minute with ample power and pump room, the extra quantity is pumped by increasing the speed less than one extra stroke per minute.

'These engines have been at work night and day alternately for more than two years. They do not appear to be adapted to a high speed. The wear and tear consist mainly in the renewal of the leather packings of the cylinder and pump-pistons. Of course these wear much faster when the water is muddy than when it is clear. They require but little attention, one of the deputies going twice or three times each shift to see that all is right, and to regulate the speed of the engine according to the quantity of water, which varies very much.'

The following has reference to a Joy hydraulic pump installation at the Clay Cross colliery for the purpose of raising water from the dip workings in the coal to a higher level, whence it is conveyed to the standage or sump, and thence lifted to 'day' by the large pumping engine. Cylinder 5½-inch diameter, 3-feet stroke, pump 8-inch diameter, 3-feet stroke. The pistons of the cylinder

and pump are attached to a common rod. The construction and action of the engine and pump are similar in all respects to the one already described. About 50 feet down the pumping shaft is the piper coal, which gives out a feeder of 45 gallons per minute. This is conveyed by a pipe down the vertical shaft 136 feet, and then turned down the engine plane to the hydraulic engine. The total length is 2,642 feet, with a vertical head of 346 feet. The falling gradient of the plane is about 1 in 12. The water is pumped from the suction well to a water level, a distance of 1,452 feet, and a vertical height of 53 feet. The supply pipe is 4 inches diameter; the suction and delivery pipes 7½ inches diameter.

'The duty of the engine under this arrangement may be stated thus. The total vertical height of the column which actuates the engine is 346 feet, which will give a pressure of 152 lbs. to the square inch. The vertical height to which the water is to be raised is 53 feet, representing a pressure of 24 lbs. per square inch. Then 152 − 24 = 128 lbs. available pressure per square inch to work the pumps. Then area of 5½ inches = 23·75 × 128 lbs. = 3,040 lbs. pressure in cylinder. Area of 8-inch pump = 50·26 × 24 = 1,206 lbs. pressure in pump, which gives or shows about 40 per cent. of duty. Or the duty may be expressed thus: The cylinder 5½ inches diameter will contain in round numbers 3 gallons. A feeder of 45 gallons per minute will fill it fifteen times, and the engine will make 7½ strokes per minute. The 8-inch pump will contain 6½ gallons, which being filled 15 times will pump 96 gallons per minute out of the suction well, which added to 45 gallons used by the engine = 141 gallons sent up the delivery pipe per minute.'[1]

DAVEY'S HYDRAULIC PUMPING ENGINE

'This engine has been designed to obviate the difficulties of wear and tear experienced with hydraulic engines having pistons and slide-valves, and gearing for working the valves. Pistons and slide-valves wear very rapidly with dirty water, but plungers are practically unaffected. In this engine there are no pistons, the power being applied and the work done entirely with plungers. The power plungers are stationary, and are made to serve as pipes to convey the water from the valve-box (to which they are fixed) to the inside of the pump plungers; these latter form the power cylinders, and are connected to each other by side-rods passing outside the valve-box. In this way the forcing stroke of one pump plunger causes the suction stroke of the other, and *vice versâ*.

'The most novel part of the engine is the valve-box. For hydraulic power no valves answer better than the single mitre-valve; if these valves get leaky owing to sand and grit, they are easily replaced by duplicates, or ground tight again. The difficulty with single mitre-valves of the ordinary type is, however, that of working them, when made of sufficient size to produce but little throttling. This difficulty is entirely obviated in the engine under notice by a device which Mr. Davey has patented. Instead of being actuated by means of metallic connections, the valves are worked under water pressure by means of a small subsidiary valve acted on by tappets from the engine at the ends of the

[1] Edmund Bromley: *Joy's Patent Hydraulic Pumping-Engine* (Trans. Chesterfield and Derbyshire Inst. Mining, Civil and Mechanical Engineers, July and October, 1871).

stroke. On this construction they may be made of any size, and a full and free water way given, so as to realise the greatest possible useful effect. By regulating the passages between the subsidiary and main-valves, the latter are made to rise and fall at any required speed, so that the beat may be entirely taken off, and the wear and tear of the valves reduced to a minimum. Each plunger communicates with a chamber in the valve-box, fitted with one inlet and one exhaust valve. The valves (which are of gun-metal working on gun-metal seats) have plungers formed on them above and below, the lower plungers being packed with double-cupped leathers as shown, while in the case of the inlet valves the upper plungers are also packed with cupped leathers. The lower plungers are thus really the rams of small hydraulic presses, and by admitting water under pressure below them the valves are lifted. Diagonal passages connect the plunger chamber of the right-hand exhaust valve with the plunger chamber of the left-hand inlet valve and *vice versâ*.'[1]

The following is an account of the pumping machinery at the Erin colliery, Westphalia, referred to a few pages back. 'The pit is 1,200 feet deep, and a pair of steam engines and hydraulic engines combined are capable of delivering the required quantity of 1,000 gallons of water per minute, or 60,000 gallons per hour, to the surface. Each engine is capable of raising 500 gallons per minute to the surface, and at the same time of supplying power to a pair of hydraulic pumping engines placed at the bottom of the pit, and employed in raising 500 gallons each per minute to the main engine.

'Each engine has a massive girder bed of cast-iron, with a 35-inch high-pressure and a 60-inch low-pressure cylinder, 6-feet stroke. The slide-valves for these cylinders are actuated by the author's [Davey's] patent differential valve-gear. The pistons are fitted with metallic packing. The pumps are double-acting ram-pumps, 12½ inches diameter, 6-feet stroke, with rams of gun-metal. The pump-rods, 5¾ inches diameter, pass from end to end of the rams, and are secured thereto by gun-metal nuts. The piston-rods and pump-rods are united in one strong wrought-iron crosshead, supported and guided in cast-iron slide-bars. The pump-valves are of gun-metal, double-beat, 11 inches in diameter, and low lift, allowing ample area in the water passages, and thus reducing friction to a minimum. The suction pipes are 10 inches diameter and the rising-main 14 inches diameter; all the joints of the pumps and pipes are of the well-known hydraulic type, made with gutta-percha.

'At the bottom of the pit, 300 feet below the main engines, is placed a pair of hydraulic engines . . . which lift 1,000 gallons per minute to the main engine, at a speed of twelve strokes per minute, whilst the latter finally force the water to the surface, and at the same time, through the column, supply power to work the hydraulic engines. The latter consist of double-acting power-rams and pumps, placed face to face on the telescopic principle. These engines are self-contained on a strong girder bed similar to that of the steam engine. The starting-valves are in the main engine room, so that the hydraulic engines can be set to work from the main engine room, although the whole of the lower part of the pit might be filled with water. As a further security a staple might be put down from the main engine room to the hydraulic engines (tubbed or otherwise made watertight) with a ladder of access, so that in the event of a

[1] Henry Davey: *Davey's Hydraulic Pumping-Engine* (Trans. Midland Inst. Engineers, October 13, 1875).

flood in the workings the hydraulic engines would still be in the dry and accessible for repairs. The pumps, which are placed at each end of the bed, are 14 inches in diameter, and of the ordinary ram type, with gun-metal double-beat valves, and brass-covered rams 12 inches diameter and 5-feet stroke. The two rams are connected to each other by two strong wrought-iron side rods, and thus alternately pull one another in their return stroke. The power rams, which are 7 inches diameter, are wholly of gun-metal, and of the same stroke as the pumps. They are connected at one end to a central valve-box, and being cast hollow, admit the pressure to the cylindrical rams of the pumps. All the bearings and glands are brass-bushed. All the packings are easy of access, and are applied only in stuffing-boxes.

'The main valve-box is placed in the centre of the engine, and contains four valves, 5¾ inches in diameter, two being supply and two exhaust, which communicate with their respective pumps. The valves are cylindrical gun-metal mitre valves, 6½ inches diameter at top, and provided at their cylindrical ends with double cup leathers. They are of large diameter and low lift, thus reducing friction and wear and tear to a minimum. The upper or cylindrical portion is of rather larger diameter than the valve proper, consequently the pressure from the main lifts this valve and admits pressure to the power ram.

'On the return stroke this valve is closed by admitting pressure on the large area at the top of the valve, whilst a corresponding but intermittent action takes place with the relief-valve. The main-valves thus rise and fall by the alternate admission and cutting off the water pressure, which is further regulated by a modification of the differential gear.' [1]

MOORE'S HYDRAULIC PUMPING ENGINE.

In Moore's system of hydraulic pumping, a steam engine at the surface works by means of tube connections a double-acting ram force-pump in the shaft or dip workings of the mine, as the case may be. Small tubes between the surface engine and the underground pump, filled with water, form what might be called a water-rod.

Without reference to illustrations it is not easy to give an intelligible description of this or any of the pumps noticed, but the following presents a good idea of the general arrangement of the Moore pump and its method of working.

'A steam engine placed on the surface works a pump at the shaft bottom, or at any point in the mine where it is convenient to fix the pump; the power is conveyed by water pressure. The engine drives two rams on the surface, moving in opposite directions; these are connected with two corresponding rams at the pump, by means of two pipes (one to each end of pump), which are filled with water, called the power pipes.

'The pump is double-acting, and is situated between the two power rams, and connected by means of a crosshead; each pump is provided with an air vessel.

'When the power rams on the surface are moved by the engine there is a

[1] Henry Davey: *The Underground Pumping-Machinery at the Erin Colliery, Westphalia* (Trans. Society of Engineers, June 12, 1876).

corresponding movement of the power rams and pump underground (the power being conveyed by the water in one of the pipes). When the engine moves in the opposite direction, power is conveyed by the water in the other power pipe to the power rams at the opposite end of pump, and gives the backward motion to the pump.

'The two columns of water in the power pipes are thus moved to and fro as if they were two reciprocating rods. The same water is always kept in the pipes, but if any were lost by leakage it is replaced before commencing each stroke from a tank on the surface.

'The working pressure on power rams is often 1,000 lbs. on the square inch, thus the fittings are very compact.

'The area of the power rams and power pipes should be so proportioned that the rams travel at a speed of about 80 feet per minute, and the speed of water in the power pipes may be about 300 feet per minute.

'The relative sizes of the plunger pump and the hydraulic rams must necessarily vary with the quantity of water and height to which it is raised, and also with the pressure at which it may be decided to work the hydraulic rams.

'This pump may be used also in a sinking pit. When used as a sinking pump it works in slides like a cage ; the whole arrangement of pump, power pipes, and rising column is suspended from the surface and is lowered as the sinking proceeds.'[1]

The pumping plant at Niddrie collieries, Portobello, has recently been increased by the addition of a powerful hydraulic pump on the Moore principle, which has just been started. This is believed to be the largest plant of the kind in the United Kingdom. The machinery on the surface of the mine consists of a compound condensing horizontal steam engine, high-pressure cylinder 18 inches, low-pressure cylinder 32 inches, working tandem, 4-feet stroke, running 45 revolutions per minute, driving by means of shafting and gearing four hydraulic rams, each 8¼ inches in diameter, with a 4-feet stroke, 7 strokes per minute. The steam pressure is 90 lbs. The hydraulic power is conveyed into the mine by means of four lines of malleable iron tubes, ½ inch thick, 4 inch internal diameter. The distance or length of each power pipe from surface hydraulic pumps to underground hydraulic pumps is 2,525 feet. The working pressure of the water in the power pipes in the mine at pump is 16 cwt. per square inch. The power pipes are connected to eight hydraulic rams in the pit, each 5¼-inch diameter. Each pair of rams is connected by means of a cross-head with a pit pump. There are four pit-pump rams, each 11¼ inches in diameter, with a stroke of 4 feet. The rising main is a column of cast-iron pipes, 10-inch diameter, having a head of 110 fathoms or 300 lbs. pressure per square inch. The quantity of water discharged is 500 gallons per minute. The pump is intended to duplicate the Hathorn-Davey direct-acting pump, and is placed alongside of it in the mine, on the second stage of the three stages or heads into which the pumping arrangements are divided, at a vertical depth of 1,410 feet from the surface. The result of a number of trials shows that the whole plant is working smoothly, efficiently, and economically. The makers are Messrs. Gibb & Hogg, engineers, Airdrie.[2]

[1] W. G. Mitchell in *The Science and Art of Mining*, January 23, 1897, p. 256. The speed of the water in the power pipes is, by a misprint in the paper quoted, given as 30 feet per minute ; it should be 300 feet. S.'M.

[2] *Op. cit.*, January 30, 1897, p. 278.

'At Balquhatstone colliery, Slamannan, there are two sets of double-acting 12-inch pumps worked by one geared engine, raising 600 gallons a minute from the bottom of a vertical shaft 65 fathoms deep. The driving cranks for the surface power rams are fixed at right angles, so that the engine is balanced. Either pump can be worked independently of the other by disconnecting the power rams at the engine, so that it forms a duplicate plant. This is found to be a very good arrangement, and several installations have been fitted up on this plan.'[1]

A Moore plant has been put down at the Cefn colliery, South Wales. The engine working the pumps has 14-inch high-pressure and 26-inch low-pressure cylinders, with 4½-feet stroke, receiving steam at 100 lbs. pressure per square inch. It is geared 5 to 1 to 3 sets of Moore's pumps. The surface rams are 4⅝-inch diameter, 4-feet stroke; the pump rams are 3-inch diameter. Two pipes are taken underground from each ram—six in all—two go down an incline for 220 yards at an inclination varying from 28 to 35 degrees, two to 543 yards, and two to 274 yards, and are 3-inch diameter. These are the power pipes; the water pipes are 6-inch diameter. It is stated that as much as from 72 to 75 per cent. of the engine power is utilised.

KASELOWSKY'S HYDRAULIC PUMPING ENGINE

The latest type of hydraulic pumping engine, and one which is attracting a little attention in English mining circles, is the Kaselowsky engine. It has not yet made its appearance in this country, but it has been introduced into a large number of German mines. The inventor is Emil Kaselowsky, of Berlin, who patented his system in this country in 1894. In default of the specification filed at the British Patent Office, June 15, 1894, which without the accompanying illustrations would be quite unintelligible, the following description of the Kaselowsky system, furnished by the Berliner Maschinenbau-Actien-Gesellschaft under date July 15, 1898, may be comprehensible. With the exception of an occasional slight verbal alteration to make the meaning clear, we have retained the phraseology and nomenclature of the original.

'This plant consists of a compressor placed overground and of a pump placed underground, which latter is worked by direct hydraulic power; both pumps are connected with each other by a high-pressure and a return water pipe.

'The compressors are single plunger-pumps which are connected directly to the through piston-rod of the steam engine. These pumps suck the return water from a tank placed near them, and press it into an accumulator of air pressure (Patent Prött-Seelhoff), which is also placed near by.

'The object of this accumulator is to prevent shocks or over-pressure in the piping and in the hydraulic machinery; and, in order to obtain this object with an absolute certainty and under all circumstances, especially when starting quickly and suddenly, there is a second accumulator of the same construction of smaller size in the underground machine chamber inserted in the pressure

[1] R. T. Moore, paper on 'Joseph Moore's Hydraulic Pumping Arrangement,' read February 11, 1893. *Trans. of the Federated Inst. Mining Engineers*, No. 177, p. 3 (quoted by permission).

pipe immediately before entering the regulator. From thence the pressed water passes by means of two distributing pistons into the starting cylinders, which are worked by hydraulic power.

'These cylinders also form the pressure plungers; this is obtained by having fixed power or starting plungers, which enter into the pressure plungers. Thereby a very simple arrangement is obtained, requiring very little space. Each two of such power and hoisting plungers are combined to one system, forming a double plunger-pump with the pump cylinders placed outward.

'Two of such pumps are placed side by side and control each other, so that no standstill can occur in the moved water columns, but a uniform movement of the water is produced in the pressing and return piping, as well as in the rising pipe, and the water flows out of the rising piping in a uniform stream, thereby the working of the pump will be perfectly easy and silent.

'The exhaust pressing water is led back by a special pipe to the return tank, placed overground, from which the pressure pumps suck, so that the same water is always used and a waste of pressing water is almost entirely obviated. The pressing water is mixed with a small quantity of soluble oil, thereby any rusting of such parts coming in contact with the pressure liquid will be prevented, and a special lubrication of the high-pressure plungers, piston-rods, etc., is quite unnecessary.

'We usually employ a working pressure of 200 to 253 atm., which offers very essential advantages compared with the much smaller pressures formerly used. These advantages consist in the far smaller dimensions required in the compressors as well as in the impulsion plungers, regulators, and water pipes, and in obtaining a much greater efficiency.

'No difficulties are experienced with our construction in procuring tightness at these pressures; on the contrary, all the packings for this high pressure require far less attention and labour than those of an ordinary steam-pipe and steam engine. These pressures are, on the other hand, quite sufficient for the greatest depths; but, owing to economy, we employ them also for smaller depths.

'Various trials made showed the total useful effect amounted to 77 to 78 per cent.—that is to say, 77 to 78 per cent. of the indicated steamwork, measured in the hoisted-up water, is effectively utilised. Thus the loss of power by the transmission will be less than the loss will be in an underground machine by condensation in the pipe, even with the best insulation.

'Therefore the advantages of this system against all others are very considerable, as follows:

'A.—*In comparison with Underground Machines.*

'1. The steam-piping leading down the pit is unnecessary.

'2. The underground room for the machinery is extremely small as compared with that of an underground machine.

'3. Much greater safety against swamping of the mine, owing to the pump being able to work under water.

'4. Two underground pumps can be worked by the same plant from overground, so that one may be worked alone or both together.

'5. At the further sinking of the mining shaft there may be placed another pump on the deeper level, and be worked by the same installation from over-

ground, the pump on the old level also working ; this may eventually be placed deeper, and be utilised as a spare pump.

'6. Applicable for any depth up to 2,000 m. or more.

'7. Acidulous or saltish water, when used for condensation in underground machines, greatly corrodes all parts coming into contact with it on account of its high temperature, which is not the case in our hydraulic working plant. The somewhat higher cost of a hydraulic plant is thus richly compensated for by the many and important advantages.

'B.—*In comparison with Overground Rod Plant.*

'1. The cost of construction is essentially smaller.

'2. The steam-consumption is very considerably smaller.

'3. The required space in the shaft is greatly reduced.

4. The safety of the work is much greater.

'5. The overground as well as the underground installation may be placed in any position and distance from the shaft.

'C.—*In comparison with Electrical Transmission.*

'1. The single parts of the hydraulic work are far less delicate, and are more thoroughly known and understood by the ordinary machinists, and easily kept in good order, therefore considerably safer in working.

'2. The hydraulic installation can work under water, while the electrical installation is affected by moist air and dust.

'3. The very high useful effect of hydraulic working will not be reached by the electrical plant, at least not in the present state of electro-technical science; . . . the best electrically worked water engine will consume at least about 1½ times as much steam as our hydraulic construction, which is demonstrated by the following :

'In electrical working the whole power of the steam engine must be transmitted by the connecting rod and the crank shaft, while in the hydraulic working the greater portion of power is transmitted directly on the pressing pump by the piston-rod, and therefore far less power will be lost by friction.

'Moreover, with the electrical plant the quick rotation of the electro-motor must be changed by means of gearings, crankshaft, and connecting rods into a slow to-and-fro motion, whereby, without regard to the other inconveniences, a loss of power of at least 20–25 per cent. will be caused, while in the hydraulic working the water pressure works directly on the pump-plunger to be moved, sustaining only a loss of about 1½ per cent. by friction of the leather collars.

'Supposing, now, in the electrical plant all useful effects for the continual working to be very high—as, for instance, for the steam engine 85 per cent., the dynamo 90 per cent., the conductors 95 per cent., the electro-motor 90 per cent., and the pump with gearing 80 per cent.—a total working degree of

$$0{\cdot}85 \times 0{\cdot}9 \times 0{\cdot}95 \times 0{\cdot}9 \times 0{\cdot}8 = 0{\cdot}523 \text{ or } 52 \text{ per cent.}$$

will be obtained, which, however, in actual working will not be reached. The useful effect of our hydraulic plant will be 77 to 78 per cent., as is proved by plant in use.

'Finally, we may point out that the overground compressor as well as the underground pumping works may also be constructed vertically.'

The Kaselowsky system is similar to that of Messrs. West and Darlington, originated many years ago, and developed in the last dozen years in the Scotch collieries by Mr. Moore. The chief features in which it differs therefrom are the use of accumulator pressure and a very long stroke, admitting of considerable reduction in the dimensions of the underground engine.

ELECTRIC PUMPS.

NOT the least of the benefits which have accrued from the application of electricity as a power transmitter has been the good service it has rendered mining. There can be no doubt that there is a great future for this agency in our mines, and in many instances it is doing work which from the situation of the property with regard to supplies could not be carried out so cheaply and conveniently, if at all. Specially is this the case where natural supplies of water several miles distant have been utilised. In all parts of the world, but particularly in the United States, British Columbia, Mexico, and Africa, are to be found electric installations. The thin metallic line has gone down the shaft and penetrated the workings to the help of the subterranean delver, either raising his ores, pumping the water, or lighting the workings—in some instances performing the whole of these services.

Whilst the possibilities of electricity seem to be unlimited, the comparative cost of its application will be a question that will naturally occur to one's mind. The financial factor will largely determine the range of its application, and the extent of its use in mining operations. It has been demonstrated that mechanically and potentially it is equal to any task performed by other agents, being both powerful, useful, convenient, and manageable. Of its utility and general handiness and convenience for dealing with water in remote, out of the way, and more or less inaccessible points, such as dips, winzes, etc., and for experimental work there can be no doubt. But these are minor pumping operations. What we should like to know is whether from an economical standpoint it is suitable for heavy and permanent drainage.

Leaving this thought for awhile, let us consider the conditions of the generation of this force, the constituents of an electrical power plant, and the general circumstances of its use.

The generating power.—It will hardly be necessary to point out that electricity is a secondary and not a prime power. In this it resembles compressed air, for which there must be an agent, such as water-power or steam, to achieve the needed degree of compression, before it can be of service. So with electricity, the dynamo which converts mechanical into electrical power must be driven by water, steam, gas or other power. Water, operating a turbine or a water-wheel, is, of course, the cheapest prime motor for generating force, reducing the cost to a minimum, and if it were universally available in adequate quantities there would be no doubt as to the position electricity would hold in mining operations. But as in only comparatively few instances is water-power obtainable, another motor—steam, gas, or oil—must be requisitioned for the purpose.

In default of water-power steam is more used than any other power on account of its economy, elasticity, and general convenience.

The *Steam-Engine* may be either of the simple, compound, or triple

expansion class, but it appears that the two latter are now most largely used. It is preferable to couple the engine direct to the dynamo, but connection by belting is the more general method; it depends upon the type of engine adopted and other circumstances.

Dynamos or *Generators* may be virtually divided into two classes—Continuous and Alternating, either of which can be employed according to the conditions and work required.

The next provision to be made is the *Main* or *Conductor* for conducting the electrical current to the motor, which in operations such as we are considering is located underground, where it is coupled to the pump. Copper is the material generally used for the circuit between the dynamo and the motor. The size is regulated by the current to be transmitted, with the loss that can be allowed. 'The classes of conductors suitable for the severe conditions of mining work are not very numerous, and differ chiefly in the kind of insulation, and the means employed to protect them from mechanical injury, and from the effects of water. Broadly there are two kinds of insulation which have stood the test of time, viz., vulcanised rubber and bituminous compounds.'[1] The cable can be located wherever it will be most out of the way. It may be run in straight lines, or curved in any direction. 'The methods of running cables down shafts and fixing them in position differ in almost every case. . . . The plans adopted for supporting cables in shafts differ widely. In all cases, however, where it is desired to give the work a permanent character, the cables must be entirely cased in wood, run in iron pipes, or heavily armoured. These three methods are not always equally applicable, for local conditions may make one of them the cheapest or most desirable.'[2]

The pair of main cables of the electric plant installed at Balgonie colliery, Markinch, Fife, by Messrs. Ernest Scott and Mountain, Limited, taking current from the dynamo to the switchboard, and from the switchboard to the bottom of the shaft, consists of 37 wires, No. 15 S.W.G., insulated in the following manner: 1st, one coat of pure Para rubber; 2nd, two coats vulcanising india-rubber; 3rd, one coat vulcanising type; 4th, the whole vulcanised together; 5th, braided hemp; 6th, coated preservative compound. They are protected by a heavy armouring of galvanised steel wires, taped, braided, and compounded over all.

The *Motor* should be preferably of enclosed type and of compact form, and constructed for mounting on the same bed-plate as the pump, which may be connected either by belt or spur gearing. Its purpose is the reverse of that of the dynamo; in other words, is the converse of it, namely, the conversion of electricity into mechanical energy.

'The functions of the two machines must now be compared. The chief conditions of working in the two cases are widely different, and these distinctions must be duly considered in the design. The dynamo will be usually driven at a speed as nearly constant as possible, and will be required to give a variable output at a constant pressure. The motor will usually be run at a fairly constant pressure of supply, and will be required to give a variable torque at a constant speed. The dynamo in most cases will be placed in a

[1] Albion T. Snell, Assoc. M. Inst. C.E., M.I.E.E., etc., *Electric Motive Power*, p. 307.
[2] *Ibid.*, pp. 309, 310.

dry engine-room, and will meet with at least as much attention and care as ordinary steam plant. The motor, on the other hand, must be in close proximity to the machine driven, and will frequently be in a dusty, dirty, and more or less exposed position; and the attendance will be most likely a few visits daily at the most. The dynamo will probably run with fairly steady loads and not be subjected to large sudden variations of output. The motor must, in the nature of things, meet with rougher usage. If the work be intermittent, the stoppages frequent, or overloading common, the motor must meet the demand, no matter how great the strain. It follows, therefore, that the motor should be built with a larger factor of safety than is usually necessary with a dynamo, and that extra care should be given to the insulation and general details.'[1]

For colliery use a special form of motor is necessary to avoid the danger that arises from what is known as 'sparking.' This is inseparable from the use of brushes and commutators, and the sparks generated may, under certain conditions, fire explosive gas. To avoid this danger the armature, commutator and brushes are enclosed in a metal case; motors thus designed are termed 'safety motors.' Mr. Snell is of the opinion that the only real safeguard is to do away with this type of motor altogether and use polyphase motors.[2]

We come lastly to the *Pump*, which is driven either by spur-gearing, worm-gearing, or by belting. Where circumstances admit of its use, rope-driving is preferable. If a long belt cannot be introduced, a short belt with jockey pulley may be the next best. Worm-gearing has a low efficiency and therefore cannot be recommended. With well-designed bedplate and bearings spur-gearing is said to give good results. Mr. A. W. K. Peirce says: 'When steadily transmitting a considerable amount of power, such as is the case when used on mine pumps, the efficiency of a single set of gears under the conditions mentioned may be as high as 96 per cent., and their life may be measured by years, not months.'[3] The type of pump used most largely in connection with electric motors is the Three-Throw Ram-pump, arranged either vertically or horizontally, the horizontal type almost exclusively when the lift exceeds 300 feet.

'I think there is no question as to the superiority of the three-throw or triplex type of pump, having the cranks following one another at angles of 120°, driven from the motor by single reduction machine-cut gears. As to whether the pumps should be of the horizontal or vertical type is largely a matter of design, and of the use to which the pump is to be put. I would rather have a well-designed vertical than a poorly designed horizontal pump for any service, but it is my opinion that for heads of over about 300 feet or so a vertical pump cannot be made sufficiently stiff and heavy to stand the strain of the gearing and the thrust of the plungers as well as a horizontal pump, unless it costs more money. As a rule, too, the vertical pump does not allow of as good an arrangement of the motor and gearing, that being single reduction, as the horizontal.'[4]

'The electric pump presents a somewhat more difficult mechanical problem than the hoist, on account of the conversion of rotary to reciprocating motion,

[1] Albion T. Snell, Assoc. M. Inst. C.E., M.I.E.E., etc., *Electric Motive Power*, pp. 13, 14.
[2] *Ibid.*, p. 342.
[3] A. W. K. Peirce: a Paper read before the South African Soc. Electrical Engineers, Johannesburg.
[4] *Ibid.*

and the importance, in most cases, of compactness and protection of the motor against water. That the problem has been satisfactorily solved, however, is proved by the large number of electric pumps of various kinds and sizes in successful operation.'

'The sinking pump is the most difficult to design, on account of the small space available for the motor, and the necessity of enclosing it in a practically water-tight case; but numerous successful pumps of this kind have been made and installed. The three-phase induction-motor is especially adapted to this work, as it has no brushes or moving contacts, and the wires can be carried through water-tight bushings in the case to the stationary terminals on the field.'[1]

Efficiency.—At full load the dynamo gives out from 90 to 94 per cent. of the engine-power, and this high efficiency is maintained through a considerable range of output; at half load it is about 85 to 90 per cent., and at one quarter load will not fall below 75 per cent.[2] The use of storage batteries, it is stated, permits a current efficiency of 94 per cent. or a total energy of 87 per cent. of the power supplied, but it is doubtful if it is got in practice. Line losses vary from 5 to 10 per cent.; in extreme cases they may amount to as much as 15 per cent. 'Care should always be taken that the conductors are well insulated and are mechanically strong. The losses in these need not exceed from 5 to 10 per cent. for almost any reasonable distance.'[3] The efficiency of the line depends upon the size and quality of the conductor, together with the length. The following extracts from a table given by Mr. Snell, besides the efficiency of various lengths and areas of conductors with three-phase circuits, give the cost of the line and the cost per h.-p. delivered by the motor. The necessity for high pressures is very apparent.[4]

For brake h.-p.	Distance in feet	Area of each conductor in square inches	Effective pressure between mains in volts	Current in each main in amperes	Efficiency of conductors per cent.	Total cost of line at 7*s.* per lb. of copper	Cost per h.-p. delivered by motor
						£	£ *s.*
100	25,000	·0067	5,000	8·75	97·0	200	2 0
200	25,000	·0067	5,000	17·50	94·0	200	1 0
500	25,000	·0134	10,000	26·25	97·5	400	16
100	50,000	·0067	7,000	6·25	97·0	400	4 0
200	50,000	·0067	7,000	13·5	92·5	400	2 0
500	50,000	·0134	10,000	26·25	94·5	800	1 12
100	100,000	·0067	10,000	4·375	97·0	800	8 0
200	100,000	·0067	10,000	8·75	94·0	800	4 0
500	100,000	·0134	10,000	26·25	92·0	1,600	3 4
100	150,000	·0067	10,000	4·375	95·5	1,200	12 0
200	150,000	·0067	10,000	8·75	91·0	1,200	6 0
500	150,000	·0134	10,000	26·25	84·5	2,400	4 16

In a list of multipolar continuous-current dynamos manufactured by Messrs. Easton, Anderson and Goolden, Ltd., the efficiency varies from 95 to 75·5 per

[1] Irving Hale, Colorado, in *The Mining and Electrical Review.*

[2] Albion T. Snell, Assoc. M. Inst. C.E., M.I.E.E., etc., *Electric Motive Power*, p. 9.

[3] F. H. Headley: *Electricity as a Transmitter of Power*, a Paper read before Mining Insts, Cornwall, January 19, 1898.

[4] *Op. cit.*, p. 383.

cent. The commercial efficiency of continuous-current plants varies, according to circumstances, from 80 to 45 per cent. The efficiency of the motor varies according to the capacity, from 90 to 80 per cent. The combined efficiency of triple plunger-pumps and motors has been stated to be as high as 75 per cent.

If we assume the efficiency of the various constituents to be as follows, namely, dynamo 90 per cent., line 90 per cent., motor 80 per cent., pump 70 per cent., we have as the combined efficiency of the plant 45·36 per cent. of the power the engine transmits to the dynamo. Without reckoning the pump the efficiency is 64·8 per cent.

'. . . An efficiency of 67 per cent. can readily be obtained even when transmitting nearly 100 h.-p. to a distance of more than two miles, and without any attempt being made to get specially good results, the whole plant being such as can be worked by unskilled men.' [1]

The following table has been prepared by Messrs. Atkinson to show the relative cost of transmitting power by compressed air and by electricity.

System	Brake h.-p. of steam engine	Brake h.-p. of motor	Distance from engine to motor in yards	Size of cable or pipe	Price of engine and dynamo or compressor	Price of cable or pipe	Price of motor	Total cost of plant without erection	Efficiency per cent.
				in.	£	£	£	£	
Electric	15·4	10	2,000	$\frac{7}{16}$	210	192	95	497	65
Compressed air	33·3	10	2,000	4	130	700	63	893	30

Compared with compressed air, the plant is less expensive, and there is the immense advantage of a smaller loss of power in transmission.[2]

'According to experiments made with the electric plant at St. John's Colliery, Normanton, and Llanerch Colliery, Monmouthshire, the efficiency of the plant, *i.e.*, the ratio between the work done in pumping and hauling by the electric motor and the work given out by the steam-engine at the surface, is as much as from 43 to 48 per cent.

'Making every allowance for the fact that these figures are given by avowed advocates of electricity, it undoubtedly seems that compressed air is at a disadvantage as regards cost and efficiency when compared with its youngest rival.' [3]

The following are examples of good work done by electric plants:

'On the 500 feet level at the Poorman Mine in the Cœur d'Alene district, Idaho, there is a double plunger pump, working through a 10-inch column, and pumping 500 gallons a minute, the power being obtained from a 250 h.-p. Thomson-Houston motor. The power house is at a distance of 1½ miles, where they have 810 feet of vertical pressure, working on 2 Pelton wheels 36 inches in diameter, and these running the Thomson-Houston generators which produce the power. Besides running the pump, this power is also used for running a compressor and concentrator.' [4]

[1] L. and C. Atkinson, *Proc. Inst. Civ. Eng.*, vol. civ., Session 1890–91, p. 89.

[2] Snell, *Electrical Transmission of Power in Mining Operations.* Paper read before the Lancashire Branch of the National Association of Colliery Managers, Wigan, September 28, 1895.

[3] C. Le Neve Foster, B.A., D.Sc., F.R.S., *Ore and Stone Mining*, pp. 172, 173.

[4] Mr. C. W. Goodale; Letter to author dated August 26, 1897.

'At the Gagnon mine an electric plant for supplying water to the concentrator has been in use for 5 years, and is in continuous and successful operation. The plant is located 3,000 feet horizontally and 95 feet vertically from the concentrator, to which it delivers 1,000 U.S. gallons of water per minute, at a velocity of 245 feet per minute through a 10-inch pipe. There is a large 100 h.-p. generator located in the engine-room, driven by leather belt transmission from a 300 h.-p. compound engine that runs the entire concentrating department. The electrical current is transmitted to the pump station by two large insulated copper wires, at the end of which is attached a 60 h.-p. motor which is driven by the current, to which is fastened a large belt pulley. From this pulley power is transmitted to a shaft on which are two pulleys, with belts connected with two pulleys on a rotary pump; it requires 40 h.-p. to run this pump. The coal consumed per h.-p. per hour has averaged 3 lbs. In smoothness of working and continuous and steady supply of water pumped, coupled with the trifling attention required, the plant has exceeded the most sanguine expectations.' [1]

It appears that the electric mine pump has only been adopted in a very few instances in Montana, but in the other Pacific States and in the Rocky Mountain district more progress has been made in this direction.

At the Collena colliery, South Wales, there is an electrical installation. The motive power is a steam-engine, 17½-inch cylinder, 3 feet stroke, made by Marshall & Son, which drives by means of ropes a dynamo or generator, made by Parker of Wolverhampton, which is capable of producing 500 volts. The first pump is a three-throw of 6-inch diameter plungers, and 12-inch stroke, capable of raising 100 gallons per minute 1,000 feet high. Below this and delivering to it is a similar pump, with 9-inch stroke, and in a drift dipping from 4 feet 2 inches to 2 feet 6 inches per yard is a smaller pump of the same type, with 3-inch plungers. The pipes through which these pumps deliver are 6, 4, and 3 inches in diameter respectively.[2]

At the Gwin mine, Calaveras County, California, a 50 h.-p. electric plant has recently (August 1897) been started to hoist coal to the bottom of a 600-feet shaft from an incline being driven to 900 feet at an angle of 30°.

The Henry Nourse mine, Transvaal, has the following electrical plant for lighting and power purposes at the surface. The steam-engine is a King's Compound Condensing, Marine type, with Corliss gear, made by Messrs. Fraser and Chalmers, Limited. The cylinders are 19 and 30 inch, and the stroke 3 feet 6 inches; the indicated h.-p. is 300. The generator is rope-driven. Eight multitubular boilers, with Green's economisers, supply steam from 100 to 120 lbs. per square inch. The generators, of which there are 4, are of the continuous-current type, with a voltage of 120; 3 of the generators have a watt output of 38 units each, and 1 of 50 units. There are 2 three-throw pumps, 12-inch plungers, driven by belting, and pumping 45,000 gallons per hour, the motors taking 37,400 watts at full load. Mr. James Whitburn, to whom the author is indebted for the foregoing particulars, writing under date August 20, 1897, says: 'The electric pumps used here generally consist of three-throw plungers. . . These are found very useful in many places such as stations for returning or forcing water up to mills, as the power can be transmitted at a small cost and requires but little attention. Small pumps

[1] Mr. W. Carkeek; Letter to author dated September 1, 1897.

[2] From information courteously supplied by Mr. J. L. Thomas, January 10, 1898.

also, at a distance, can be driven more economically by electricity than by steam. . . Within the mine the electric motor is usually connected directly by a pinion, belting being very rarely used underground. . . . The electric pump is too delicate for sinking purposes generally.'

Messrs. Fraser and Chalmers, Limited, have made pumps of their 'Germania' Triple Plunger type, 3½ × 12 inch with Riedler valve gear, for the Rand mines, South Africa, to pump 150 gallons per minute against a head of 2,300 feet, running at 125 revolutions per minute, and driven by ropes from the motor. When, as in some groups of the Rand mines, a number of mines combine and have a common power plant, larger units can be employed and higher efficiency obtained.

An electrical installation at the Newbattle colliery, Dalkeith, comprises two 15½-inch horizontal condensing engines, 2 feet 9 inches stroke, fitted with Corliss valve gear, each capable of developing 150 effective h.-p. with a steam pressure of 100 lbs. per square inch; two dynamos (Messrs. Ernest Scott and Mountain's 'Tyne' type), each equal to an output of 60,000 watts, *i.e.*, 120 amperes at an E.M.F. of 500 volts, at an approximate speed of 600 revolutions per minute, two motors each of 60 h.-p., and two sets of vertical three-throw pumps, 7½-inch plungers, and 12-inch stroke, each capable of delivering 200 gallons per minute against a head of 650 feet, when running at a speed of about 45 strokes per minute.

The current from the dynamos to the pumps is conveyed by four cables, the core of each consisting of 19 wires 15 B.W.G. insulated with a thick coating of bituminised fibre. The cable is then very heavily armoured with galvanised iron wires, the inner armouring consisting of 29 wires, No. 11 B.W.G., and the outer armouring of 35 wires No. 11 B.W.G.

The power is transmitted from the countershaft, which runs in four bearings to the pumps by means of two pairs of helical spur wheels and pinions, each pair of wheels being capable of transmitting the whole power if required. The motors drive the pumps also by two belts working on to two double-shrouded pulleys on the countershafts; each of the belts is capable of transmitting the whole of the power.

Two main starting switches are provided and fixed in the pump-house, so that either set of pumps may be started as required, and the speed also regulated according to the duty which they have to perform.

The following particulars refer to an electric motor and pump made by Messrs. Easton, Anderson and Goolden, Limited, for La Concorde colliery, near Liège, Belgium. The pumps are of the three-throw (or triplex) ram type, 6-inch diameter and 15-inch stroke. The lift is 1,350 feet. The motor is the company's 100 C.G. pattern, specially designed for use in fiery mines, the motor as well as the switches being enclosed. The suction water is pumped from a depth of about 10 feet by a small centrifugal pump driven by the main electric motor into a suction tank, from which the main three-throw pumps draw their water, thus having a slight head upon the suction valves, which is found to be advantageous when working under high pressures, as in this case.

The final readings of a 26 hours' continuous run with the plant under full load were as follows:

Volts at motor, 460; amperes, 110; revolutions of motor, 479 per minute; revolutions of pump, 31·3 per minute; electrical horse-power, 67·8; pump

horse-power, allowing 5 per cent. for slip, 56·0; total combined efficiency of motor and pump, 82·5 per cent.; total head of water, 1,350 feet.

Cost compared with compressed air.—Of the efficiency and cost of electric transmission Messrs. Atkinson give the following figures. To transmit 10 h.-p. a distance of 2,000 yards it will require for the electric system 15·4, and for air, 33·3 B.H.P. on the steam-engine. The cost will be 497*l.* and 893*l.* respectively, and the efficiency of the electrical plant 65 per cent., compared with 30 per cent. for the air plant.

Mr. W. C. Mountain has prepared an estimate of the approximate cost of a steam-power plant of ten horizontal engines each of 25 effective horse-power, including boilers, steam-pipes, etc., and an electrical-power plant of the same capacity.

No. 1. Steam-power Plant.

	£
4 boilers, 30 feet × 7 feet, complete with fittings, etc.	1,400
Foundations	500
10 horizontal steam-engines, each 35 I.H.P., or say 25 E.H.P., at 160*l.*	1,600
Main steam and branch pipes	600
Erecting 4 boilers, 10 engines, and 10 lengths of piping	500
Foundations for 10 engines, at 20*l.* each	200
Total	£4,800

No. 2. Electric Plant.

	£
2 Lancashire boilers, 30 feet × 7 feet, working pressure 120 lbs. per square inch, complete with fittings, etc.	700
1 compound horizontal condensing steam-engine of 400 I.H.P.	950
Foundations for engine, boilers, dynamos, etc. (exclusive of chimney)	300
1 dynamo, output say 225 units	1,000
Driving ropes	50
Main switchboard with measuring instruments	100
10 electric motors, each 25 effective h.-p. at 140*l.*	1,400
Cables for ditto, say 20*l.* each	200
Foundations for ditto, say 5*l.* each	50
Erection of plant, say	250
Total	£5,000

The following is the approximate cost per annum of 3,000 hours for maintaining the steam and electric plant respectively, on the assumption that the ten small engines will each consume 40 lbs. of steam per I.H.P. per hour, or say 56 lbs. per E.H.P., and to this an allowance of 20 per cent. has to be added for condensation in steam pipes, making the total consumption of steam equal to 68 lbs. The evaporative efficiency of the boilers is taken at 6 lbs. of water per lb. of coal, considered an ample allowance for the class of coal used in most engine works. Therefore the consumption of coal per E.H.P. will be, say, 11 lbs. per hour.

In the electrical plant the coal consumption is based on the assumption that the engines will require 15 lbs. of steam per I.H.P. per hour, and the I.H.P. is taken at 400. The boiler efficiency is taken at 6 lbs. of water per lb. of coal, which will be, say, 2½ lbs. of coal per I.H.P. per hour.

Steam Plant.

	£	s.
Coal consumption, 3,683 tons at 6*s.* per ton	1,104	18
Labour, 7 men at 30*s.* a week, 10*l.* 10*s.* per week, for 52 weeks	546	0
Water for boilers, 7,140,000 gallons at 6*d.* per 1,000	178	10
Oil for ten engines at 7*s.* 6*d.* a week	195	0
Interest on capital outlay, 4,800*l.* at 5 per cent.	240	0
Depreciation, 5 per cent.	240	0
Total	£2,504	8

Electrical Plant.

	£	s.
Coal, 1,334 tons at 6*s.* per ton	400	4
Labour, 3 men (1 attending to electric motor) at 30*s.* per week, 4*l.* 10*s.* per week for 52 weeks	234	0
Water for boilers, 1,800,000 gallons at 6*d.* per 1,000	45	0
Oil for engine and ten motors at 30*s.* per week	78	0
Interest on capital outlay 5,000*l.* at 5 per cent.	250	0
Depreciation, 5 per cent.	250	0
Total	£1,257	4

The actual saving in favour of the electrical plant would thus be 1,247*l.* 4*s.* per annum, so that the total cost of the plant would be saved in say four years compared with the steam plant, which would cost practically as much money. The above figures work out 10*l.* per annum for an E.H.P. by a steam plant and 5*l.* per annum by an electrical plant.[1]

Messrs. Siemens Brothers, Ltd., calculate that, taking into account the long lengths of shafting that had to be driven in the old steam plant of 1,446 I.H.P. at the Woolwich works, not more than 60 per cent. or 867 brake h.-p. was utilised. On adopting electric transmission the efficiency rose to 77·7 to 82·2 per cent., and there are now 1,407 B.H.P. available at the motors, and 240 h.-p. for lighting, the generating plant having a reserve power for many more motors. The outlay per brake h.-p. was 30 per cent. higher in the old steam plant than in the present electrical station plant.[2]

Messrs. J. C. Howell state: 'We recently replaced two steam-pumps underground by two three-throw pumps driven by electric motors, supplied with current from a steam-engine and dynamo on the surface. The coal consumption was at once reduced from 67 tons per week to 34, although some additional 12 horse-power was absorbed for electrically driving an underground fan.'[3]

[1] W. C. Mountain: *The Design and Efficiency of Plant for the Transmission of Power by Electricity*, Paper read before the North-East Coast Inst. of Engineers and Shipbuilders, January 15, 1895 (quoted by permission).

[2] C. C. Longridge, M.F.I.M.E., M.I.M.E., *The Economies of Electric Power Plant* (*vide Mining Journal*, November 21. 1896).

[3] *Ibid.*

Figs. 242–244 are illustrations of Messrs. Ernest Scott and Mountain's [1] 'Tyne' Dynamo, Three-throw Ram Pump, and Centrifugal Pump respectively. The latter is coupled to a motor of 120 h.-p., and is capable of delivering 1,000 gallons per minute against a head of 130 feet. Fig. 245 represents the

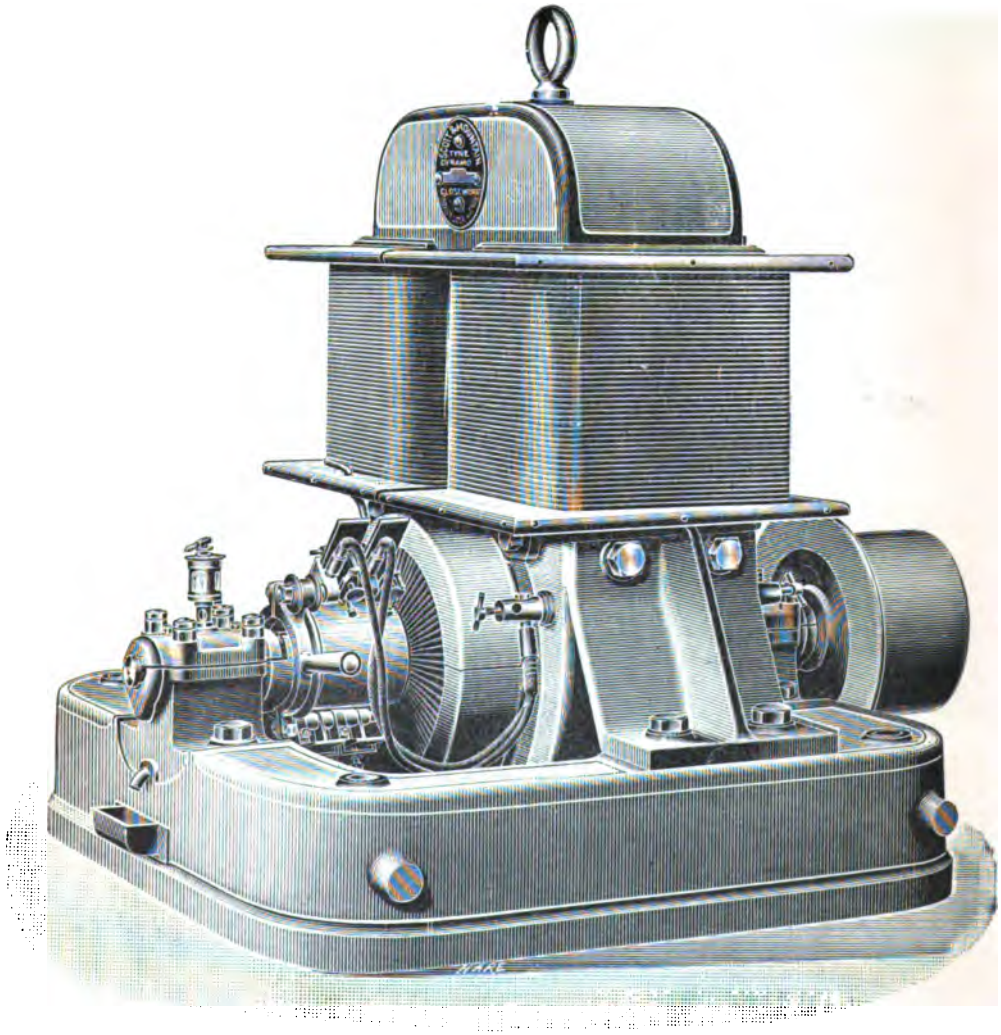


FIG. 242.—Ernest Scott and Mountain's 'Tyne' Dynamo.

'Worthington' Electric Mine Pump, and Fig. 246 the 'Germania' Pump (Riedler principle) for electric driving, and is made by Messrs. Fraser & Chalmers, Ltd.

[1] Address: Close Works, Newcastle-on-Tyne.

Reverting to the inquiry with which we began, the following would appear to be fairly deducible from such data as are available :—Where power has to be transmitted to distant points electricity gives a higher efficiency than

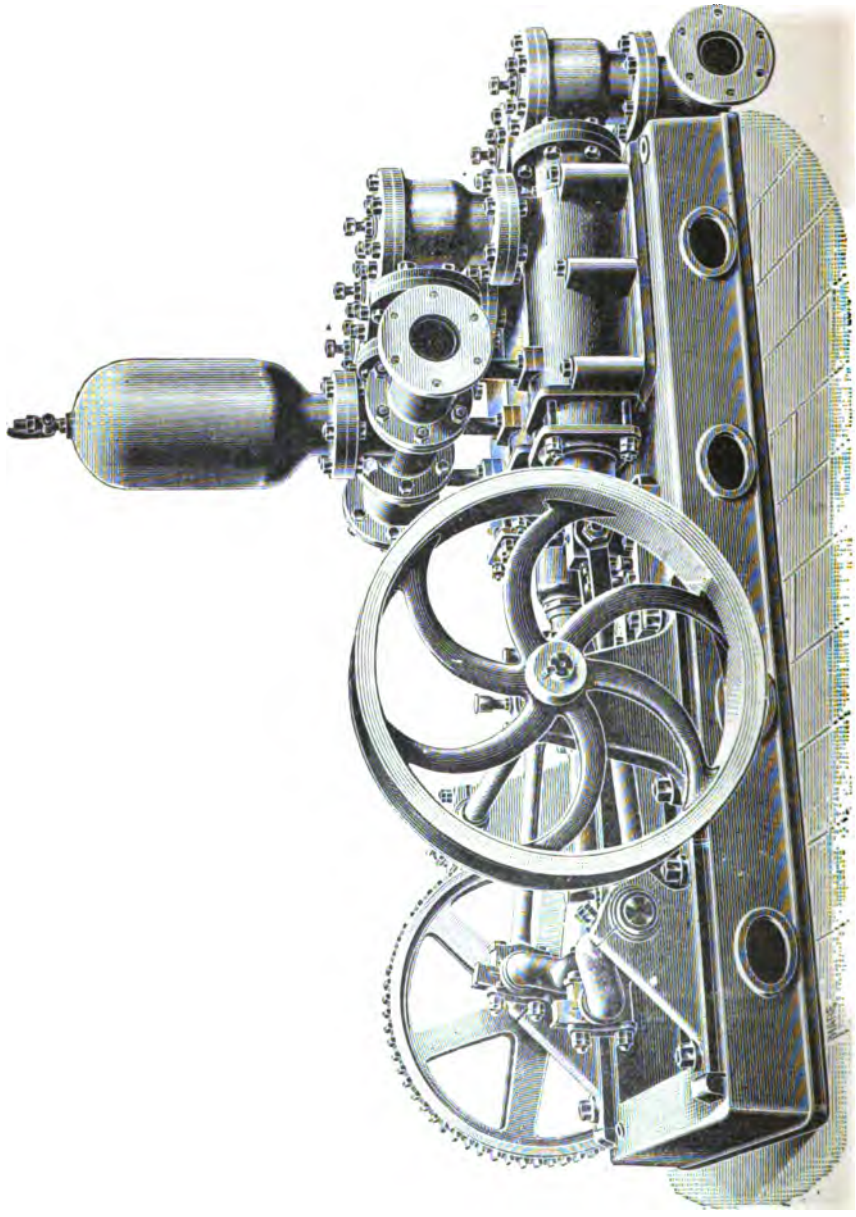


FIG. 243.—Ernest Scott and Mountain's Three-throw Ram Pump, for electric driving.

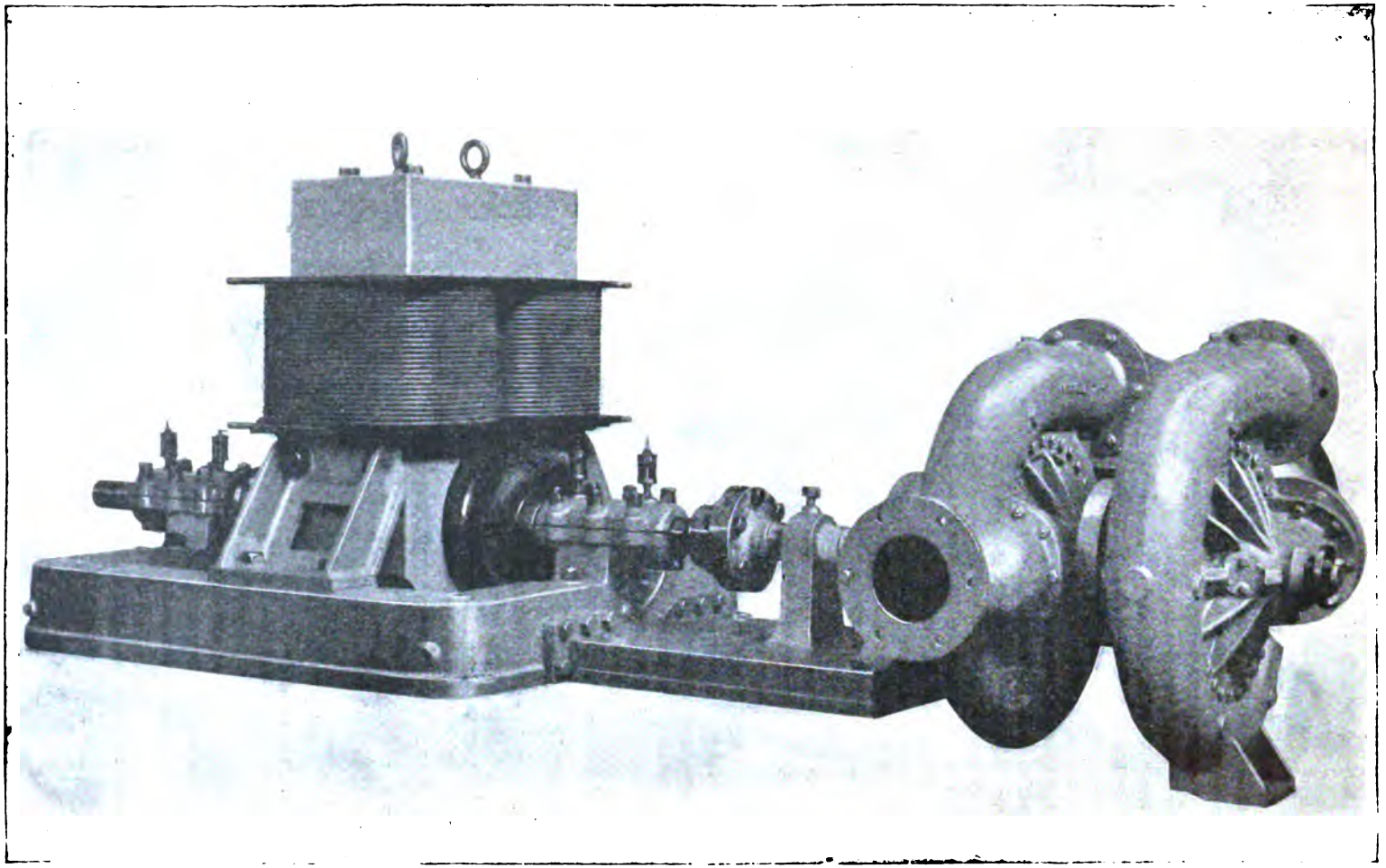


FIG. 244.—Ernest Scott and Mountain's Centritugal Pump, coupled direct to Electric Motor.

steam and is consequently cheaper. Where the electricity is applied as a central power for a number of works, mines, etc., its superior efficiency to steam is most manifest. In cases of very long distance transmission, such as the

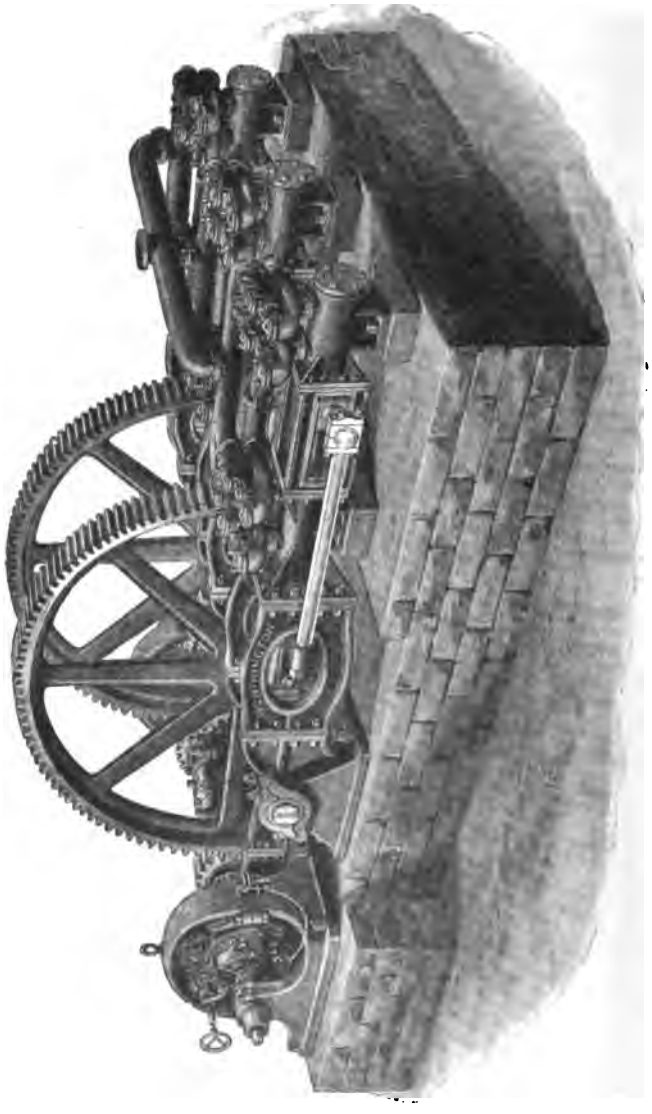


FIG. 245.—The 'Worthington' Three-throw Electric Mine Pump.

utilisation of water some miles from a factory or mine, no other system is comparable to it. For operating pumps in the inner parts of a mine, electricity is a most convenient form of power, although of course it would not pay to instal a

plant for very small operations where pumping machinery is already laid down, and power is available for working a small steam-pump.

Whatever may be the result as regards the future of steam-pumps it does

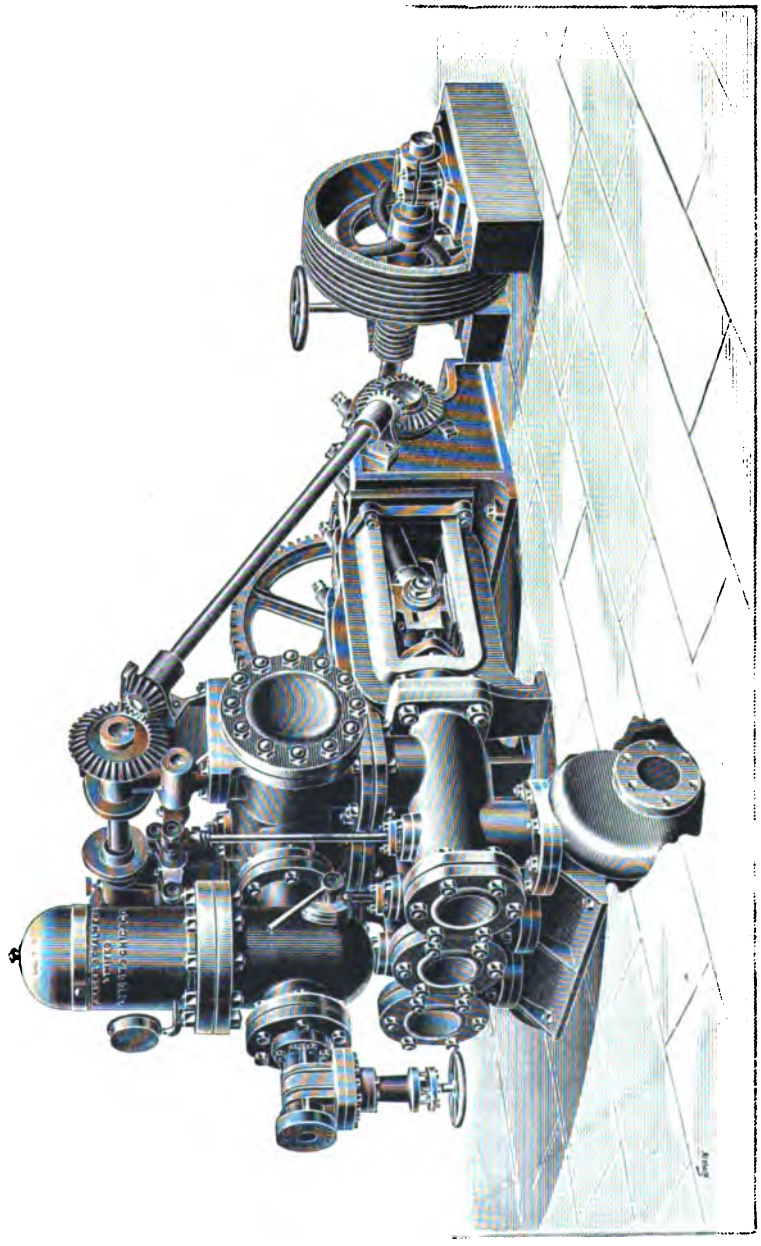


FIG. 246.—The 'Germania' Three-throw Mine Pump for electric driving.

not appear to be probable, with our present knowledge of the potentialities and economies of the electrical transmission of power, that it will be able to oust the Cornish engine and its congeners from their position as the premier pumping agents for deep, heavy, and permanent drainage.

HOLMAN'S AIR WINCH

The little engine illustrated opposite (fig. 247) is a handy and useful auxiliary for both pumping and winding where compressed air is available for operating it. It was introduced into some of the leading Cornish mines a few years ago, not only for pumping and winding from shafts or winzes, but also for changing pitwork, lowering rods, raising, lowering and adjusting boring plant, and generally for facilitating the operations of shaft sinking with rock drills. It is infinitely superior to the horse-whim, working with far greater economy and speed, and the old, laborious, and dangerous method of drawing stuff by hand labour and a tackle or windlass is entirely dispensed with. It is also very useful for hauling up miners quickly after charging the holes and lighting the fuses, dispensing with a chain ladder, which is a slow and sometimes dangerous process. As a means for pumping out water whilst sinking it has been found much more economical than a heavy, cumbrous lift attached to the main engine, which is generally in the way and often gets damaged when blasting.

The following are a few examples of good work done in Cornish mines by these little appliances. At Carn Brea 300 fathoms of the principal skip road were lowered by the aid of this simple machine. At Dolcoath important services were rendered when the 'run' took place in September 1893. By using three of these machines the bottom of the mine was kept 'in fork' (drained). Captain Thomas, the managing director, has informed the author that they have four in use, drawing from winzes varying from 12 to 15 fathoms deep. In some instances they have hauled stuff as high as 50 fathoms, from one level to a higher, whence it was trammed out to the shaft. The compressed air was supplied at a pressure of 70 lbs. per square inch.

At East Pool Mine (where three of these engines are at work), on resuming pumping after the engine had been idle for repairs, it was discovered that the shaft below the 200 feet level, which is 12 fathoms by 11 feet by 7 feet, and 4 fathoms of levels 7 feet by 6 feet, were full of water. One of these engines 'forked' the water in 27 hours, the 'coming' water being equal to three hours.

As a winding engine, worked with steam, it has done remarkable work at West Wheal Peevor. It was fixed at the 36 fathom level (or 75 fathoms below surface) and about 15 fathoms in from the shaft. Steam was conveyed to this down the shaft, and in the level through pipes from the pumping-engine boiler. It drew all the stuff broken for the stamps from the 36 to the 80 fathom level (or 40 fathoms deep), which was the chief portion of the tinstuff broken in the mine. At least 40 men were engaged on an average in these levels, and the whole of the stuff broken by them was drawn by this machine.

Several of these engines are at work at Rio Tinto and other Spanish mines, in South America, Australia, New Zealand, the Transvaal, etc. It is made in double or single cylinders, from 4 inches to 8 inches in diameter. The makers are Messrs. Holman Brothers, Camborne, Cornwall.

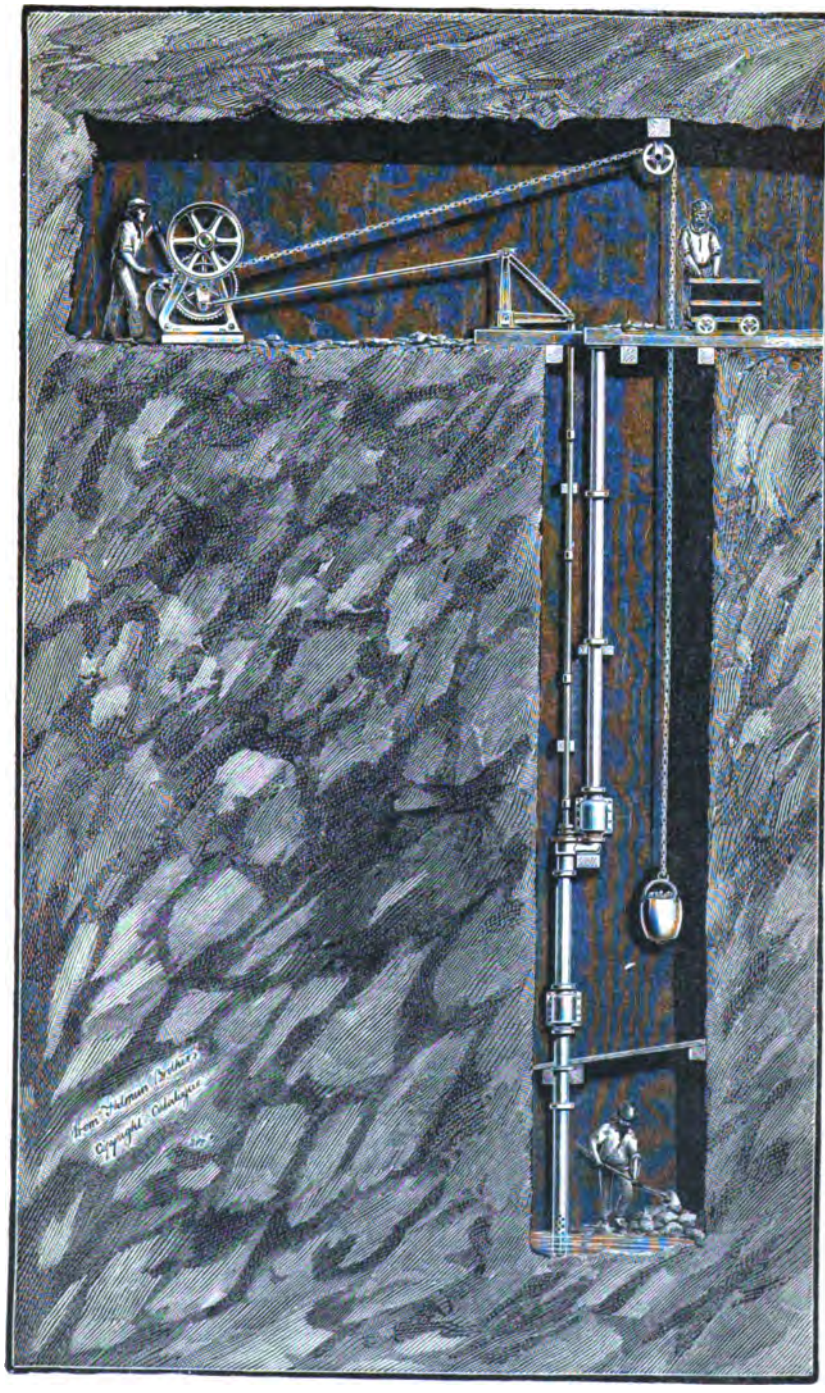


FIG. 247.—Holman's Air Winch.

HYDRAULIC AND OTHER MEMORANDA

WATER :—

1 *cubic inch* . . .	= ·0361 lb., ·577 oz., 253·18 grains.
12 *cubic inches* . .	= ·434 lb.
1 *cubic foot* . . .	= 62·3 lbs., 997 ozs., 6·23 gallons.
1 „ „ . .	= 7·476 United States gallons.
1·8 *cubic feet* . .	= 1 cwt., 11·2 gallons.
35·84 *cubic feet* .	= 1 ton, 224 gallons.
277·27 *cubic inches*	= 1 imperial gallon.
231·0 „ „ .	= 1 United States gallon.
1 *cylindrical inch* .	= ·0284 lb.
12 *cylindrical inches*	= ·341 lb.
1 *cylindrical foot* .	= 49·1 lbs., 4·91 gallons.
2·28 *cylindrical feet*	= 1 cwt.
45·64 *cylindrical feet*	= 1 ton.
1 *lb.* . . .	= 27·712 cubic inches.
1 *cwt.* . . .	= 1·79 cubic feet, 11·2 gallons.
1 *ton* . . .	= 35·80 cubic feet, 224 gallons.
1 *United States gallon*	= ·83 imperial gallon.
Ice: 1 *cubic foot* .	= 58·5 lbs.

STEAM :—

27·222 *cubic feet at atmospheric pressure* .	= 1 lb.
1 *cubic inch of water evaporated at atmospheric pressure*	= 1 cubic foot of steam (approx.).
Specific gravity at atmospheric pressure . .	= ·411 that of air at 34° Fahr.

COAL :

Evaporative efficiency of coal . .	Varies from 5 to 10 lbs. of water per lb. of coal. Under ordinary conditions of working 6 lbs. may be taken as a fair average (assuming temperature of feed water 212°).
1 *cubic foot of Welsh anthracite* . . .	= 58·25 lbs.
1 „ „ *Welsh bituminous and Scotch* . .	= 53 lbs.
1 „ „ *Lancashire and Newcastle* . .	= 50 lbs.
Cubic feet of coal × ·0345 . .	= tons.

AREAS, CONTENTS, AND CAPACITIES :—

Dia. of circle or cylinder × ·7854 . .	= area.
Dia. × 3·1416	= circumference.
144 *square inches*	= 1 square foot.
9 *square feet*	= 1 square yard.
1,728 *cubic inches*	= 1 cubic foot.
27 *cubic feet*	= 1 cubic yard.

Area of internal dia. of cylinder × *depth* . . . = cubic capacity.
Cylinder 1 *inch dia.*, 1 *foot long* . . . . . = ·034 gallon.
Square dia. pump in inches × ·034 × *speed in feet per min.* = delivery per min.

For large cylinders where both dimensions are in feet :—

Square of dia. × *depth* × 4·897 = gallons.

The following is sufficiently accurate for ordinary use, and is easily calculated[1] *:—*

Square of dia. in feet × *five times the depth in feet* = gallons.

[By deducting 2 per cent. the exact quantity is more nearly ascertained.]

Square of dia. in inches = lbs. of water for 3 feet long ÷ 10 = gallons.

To find the approximate gallons of water raised by pump per minute, at 100 *feet piston speed :—*

Square dia. of water cylinder × $3\frac{1}{2}$.

To find the diameter of a pump-cylinder to raise a given quantity of water per minute (100 *feet of piston speed being the standard*).

Number of gallons ÷ $3\frac{1}{2}$ *; then extract the square root, and the product will be the diameter in inches of the pump-cylinder.*

Pressure = the area of the steam piston × steam pressure.
Resistance = the area of the water piston × water pressure.

A margin must be allowed between the power and the resistance to move the pistons at the required speeds, say from 20 to 40 per cent., according to speed and other conditions.

Quantity of water which an engine will pump from a given depth :—

I.H.P. × 550 ÷ depth of shaft in fathoms ; or

Let H = horse-power of engine
F = depth of shaft in fathoms
G = quantity of water in gallons per minute

Then $G = \frac{H \times 550}{F}$

$F = \frac{H \times 550}{G}$

$H = \frac{F \times G}{550}$

PRESSURES :—

If the base be circular :—

Square dia. in inches × ·34 = weight in lbs. of one foot in height.

By multiplying by the number of feet high the pressure is found.[2]

If the base be square, multiply by ·434.

To find the pressure in lbs. per square inch.

If the base be circular :—Height in feet × ·341.

If the base be square :—Height in feet × ·434.

[A ready way, approximately, is to take half the height in feet. The difference is on the side of safety. For pressure per circular inch take one-third the height in feet and add 5 per cent.]

[1] Rev. W. N. Griffin in *The Engineer*, August 9, 1878.
[2] Mr. Telford's *Memorandum Book*.

BOILERS :—

The term *horse-power* as applied to Boilers represents the evaporative capacity in cubic feet of water per hour. The quantity of coal required to evaporate a cubic foot of water varies between 6 and 12 pounds, according to the construction, heating surface and other conditions of the boiler and fuel.

The best designed boilers, well set, with good draught and skilful firing, will evaporate from 7 to 10 lbs. of water per pound of first-class coal. The average result is from 25 to 60 per cent. below this.

In calculating the horse-power of tubular or flue boilers, 15 square feet of heating surface is considered equivalent to one *nominal* horse-power.

One square foot of grate will consume on an average 12 lbs. of coal per hour.

CONDENSERS AND CONDENSATION :—

The effect of a good Condenser and Air-Pump should be to make available about 10 lbs. more mean effective pressure, with the same terminal pressure ; or to give the same mean effective pressure, with a correspondingly less terminal pressure. When the load on the engine requires 20 lbs. M.E.P., the condenser does half the work ; at 30 lbs., one-third of the work ; at 40 lbs., one-fourth, and so on. It is safe to assume that practically the condenser will save from one-fourth to one-third of the fuel, and it can be applied to any engine, cut-off, or throttling, where a sufficient supply of water is available.

Condensing engines require from 20 to 30 gallons of water to condense the steam represented by every gallon of water evaporated ; approximately for most engines from 1 to 1½ gallons per minute per I.H.P. Jet condensers do not require quite as much water for condensing as Surface condensers.

Surface condensers should have about two square feet of tube (cooling) surface per horse-power of the steam engine. It is absolutely necessary to place air-pumps below condensers to get satisfactory results.

HORSE-POWER :—

Horse-power may be either *Nominal*, *Indicated* or *Effective* ; the latter is sometimes known as *Brake* Horse-power. The first-named bears no relation whatever to either Indicated or Effective, and is determined without regard to either steam, pressure or speed. It is usually obtained by dividing the square of the diameter of the cylinder in inches by 10. Another rule is to multiply the square of the diameter of the cylinder in inches by the cube root of the stroke in feet, and divide the product by 15·6 for a high-pressure engine, and for a condensing engine square the diameter of the cylinder in inches, multiply by the cube root of the stroke in feet, and divide by 47. The term 'Nominal Horse-power' really means very little ; it is arbitrary and varying, and is properly becoming obsolete.

Indicated Horse-power is determined from indicator diagrams, showing the distribution of steam in the cylinder, combined with the speed at which the engine runs.

For Indicator Diagrams—

$$\frac{\text{Area of cyl.} \times (2 \text{ stroke})}{33{,}000} = \text{constant.}$$

Constant × (mean pressure × piston speed) = I.H.P.

One Horse-power = 33,000 foot-pounds.

Cornish engineers adopt the following rule for calculating the horse-power of the Cornish engine :—

Mean pressure per square inch of piston × area of piston in inches × piston speed per minute in feet with steam on ÷ 33,000, thus :

A = lbs. per sq. inch on piston
B = area of piston in sq. inches
C = speed of piston in feet per minute, with steam on.
x = horse-power.

Then $\frac{A\ B\ C}{33{,}000} = x.$

The area of the cylinder in inches × average steam pressure in lbs. per square inch × speed of piston in feet per minute ÷ 33,000 = Indicated Horse-Power.

To find the horse-power necessary to raise water to a given height :—

Total weight of water in lbs. to be raised per minute × height in feet ÷ 33,000.

[An allowance of 25 per cent. should be added for water friction, and a further allowance of 25 per cent. for loss in steam cylinder.]

DUTY :—

'Duty' is a term first used by James Watt in connection with the Cornish engine, and is now variously expressed. It originally denoted the number of pounds of water lifted one foot by the consumption of a bushel (94 lbs.) of coal, and was, and is still arrived at by attaching a counter to the engine beam which registers the number of strokes, and the work was calculated from the number and depth of the various lifts, the size of the plungers and buckets, and the number of strokes made, and an account was kept of the quantity of coal burnt. From such data the duty per bushel is easily ascertained. Since June 1856, 112 lbs. have been taken as the coal standard.

For a simple rule for reducing duty in millions of pounds to pounds of coal per I.H.P. per hour, by which engineers outside of Cornwall generally express duty performances, see p. 203. It is becoming a common practice to state pounds of steam used, which is a better index to the efficiency of the engine ; see page 209.

In the following method of calculation adopted by Chief Engineer George H. Bailey, of Newark Water Works, at the official test of the Worthington Engine in 1870, the standard of coal is 100 pounds.

Area of Plunger in sq. in.		Pressure per sq. in. in lbs.		Load in lbs.		Feet moved per hour by Plunger.		Constant.		Duty
373·85	×	75·68	=	28,393	×	$\frac{10{,}908{\cdot}4}{400}$	×	100	=	77,157,840

Coal per hour in lbs.

Or in another way, thus :—

Displacement per stroke in cubic feet.		Strokes per hour.		Weight of water per cubic foot in lbs.		Height in feet.		Constant.		Duty.
10·4042	×	2,722	×	62·5		174·82	×	100	=	77,358,478
				400						
				Coal per hour in lbs.						

Also the following formula adopted by Frederic Graff, Chief Engineer, Water Department, Philadelphia, for the engines under his charge :—

$$\frac{P \times V \times H \times 100}{F} = \text{Duty.}$$

'Wherein P represents pounds of water delivered per stroke, as ascertained by measurement of the plungers and calculation of their displacement ; V, the number of strokes made during the trial ; H, the head pressure in feet, including friction through the main, as ascertained by gauges placed on the ascending main, just beyond the air chamber ; F, the number of pounds of coal actually consumed during the trial, not deducting ashes or clinkers, neither reckoning the coal used in getting up steam nor banking fires.'[1]

[1] Henry R. Worthington, *The Worthington Steam Pumping Engine*, pp. 95, 96.

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NOTE.— *The names of places where engines are at work will be of service to those who may wish to examine them and make inquiries as to their merits in practice.*

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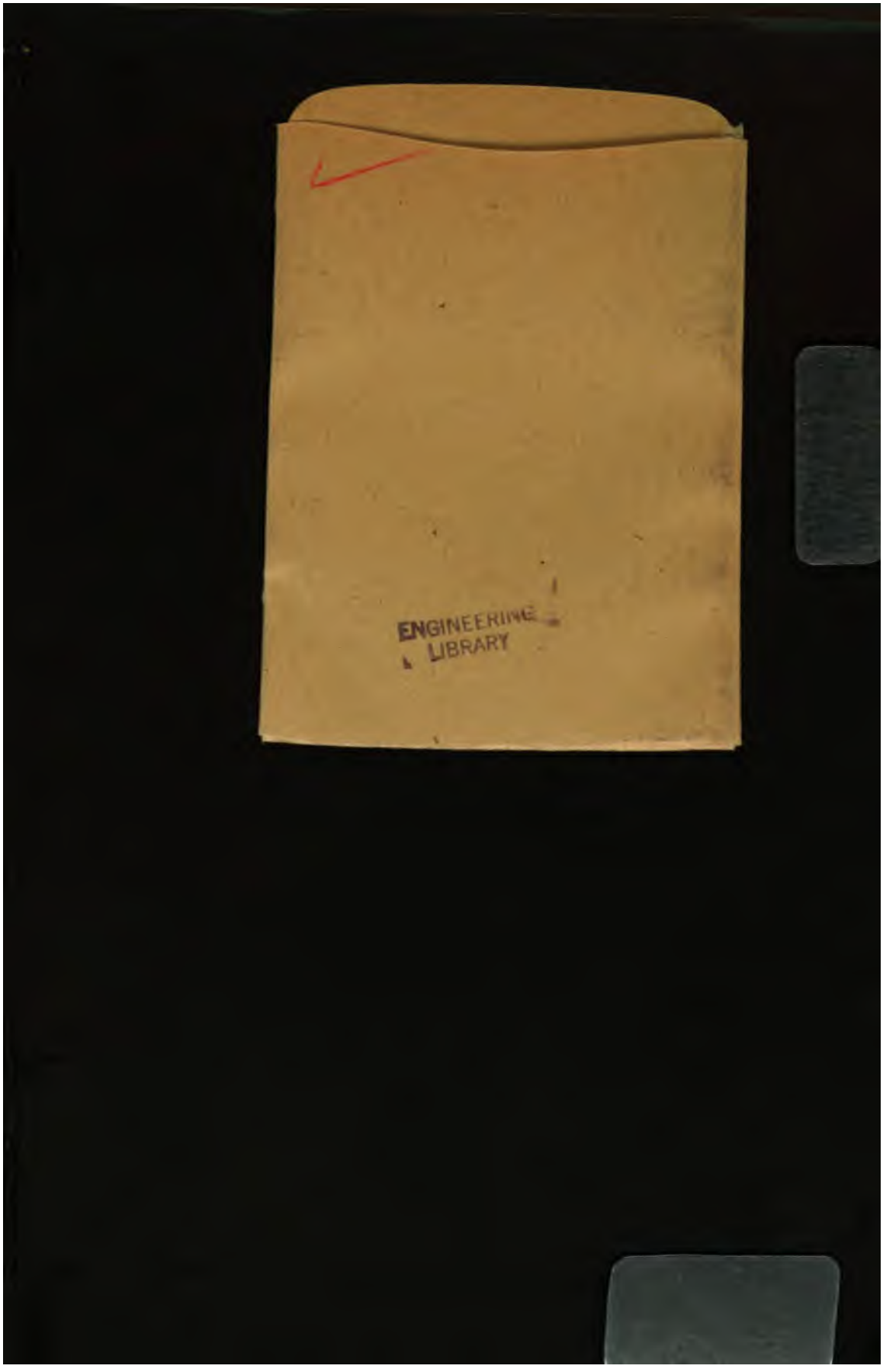
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